A HISTOLOGY OF THE BODY TISSUES

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With a Consideration of Their Functions

BY

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PREFACE

THIS book does not pretend to compete with the many and excellent textbooks on general histology which are already published. Its aim is rather to bridge the gap between the brief references to the tissues of the body to be found in books dealing primarily with anatomy and physiology, and the detailed accounts in the textbooks of pure histology. A further aim has been to emphasise the functional significance of the tissues. For this reason I have omitted unnecessary details of their structure, while I have stressed their physical and physiological properties and correlated these with the functions of the tissues in the various parts of the body.

I have not dealt with the structure and functions of the organs since descriptions of these can be found in most anatomy and physiology textbooks. I have, however, included in the illustrations sections of organs which demonstrate the integration of the various tissues in their structure.

The chapter on the preparation of tissues contains all that is necessary for the average student of elementary histology in order to understand the appearance of the tissues and organs as seen under the microscope, but it does not attempt to give instruction in the carrying out of the techniques.

Apart from the line diagrams in the text itself, all drawings were made directly from micro-preparations. In these, I have purposely given a somewhat simplified representation of the microscopic appearance in order to emphasise the characteristics of the particular tissue under consideration. It is for this reason that I have chosen to do my own illustrations rather than rely on photomicrographs. On the other hand, I have avoided a too diagram-

matic treatment, since my object is not only to help the student who has access to both microscope and material to recognise the various structures, but also to give the student who has no such ready access a more accurate visual conception than it is possible to obtain from diagrams.

I have been most fortunate in the help I have received in the writing of this book. In particular I should like to thank Professor E. M. Killick, Dr. H. S. D. Garven, and Dr. N. M. Hancox for their kindness in reading and criticizing the text; Mrs. E. Hermes for her many helpful suggestions; Miss Eileen Parker for her assistance with Chapter II; Mr. G. Patrick Meredith for his advice concerning the method of illustration; and Miss M. E. Hogg for her help in checking magnifications and references. My thanks are due also to Mr. H. Morriston Davies for much encouragement and advice and for his help in reading the proofs.

I should like to express my very real gratitude to Mr. C. Macmillan and Mr. J. Parker, of E. & S. Livingstone Ltd., whose co-operation, expert advice and unending patience have not only made the publication of this book possible, but have added so much pleasure to its preparation.

M. G.

LIVERPOOL, 1950.

FOREWORD

SPECIALIZATION in the biological sciences makes inevitable some degree of division into separate categories. Most unfortunately this schism is marked between morphology and physiology, to the detriment of both.

A textbook on Histology can all too easily deal with nothing but microscopic structure. This pitfall Miss Gillison has avoided. She takes every opportunity of pointing out the relationship of form to function, and consequently lays a sure foundation of physiological knowledge.

Illustrations are of necessity a feature of texts in histology. Photomicrographs of actual sections are, in theory, to be preferred. Yet, in an elementary book, there is much to be said for drawings of "ideal" sections. The preparation of the drawings has been a labour of love on the part of the author. They are true in all essential particulars to photomicrographs of actual sections, but retain the clarity and selective emphasis of good drawings and diagrams.

The scope in a book of this size is necessarily restricted, and has therefore been wisely limited to a study of the tissues. The intention is to meet the needs of students of physiotherapy and physical education. The integration of microscopic structure and physiological activity is so happy that the book could equally well serve all students as an introduction to animal biology.

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January, 1950.

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CHAPTER I

INTRODUCTION

General biological principles necessary for the understanding of subsequent chapters—the nature and properties of protoplasm; the structure and functions of animal cells; the arrangement of specialized cells into tissues, organs and systems.

PROTOPLASM

LIFE is inseparable from protoplasm. Living things, however different they may be in their outward appearances, contain in their structure a material common to all of them. This substance is called protoplasm. It has been termed "the physical basis of life," as it is in the protoplasm that all the reactions producing the phenomenon of life occur.

This living substance exists in microscopically small portions, called cells. The size of a plant or animal is dependent to a great extent on the number of cells entering into its formation; the largest species consist of millions of cells, while the smallest are formed of a single minute mass of protoplasm, and may be considered to be unicellular. In many plants and animals the cells do not form the whole of the body, but they always constitute the vital elements of each part. The diversity of appearance, of colour and of surface texture of plants and animals is due largely to the pigments and other materials formed by the activity of the protoplasm. Such materials help to form the hard external or internal structures, like the bark of a tree, the shell of a crab or the skeleton of the human body, which allow the organism to grow to a much larger size than would otherwise be possible and to assume a definite characteristic shape.

Protoplasm is a colourless, slightly opaque, jelly-like substance. During life its consistency varies continually between a gel and a sol. In the former condition it resembles a starch solution which has been allowed to cool, while in the latter state it is more liquid. It is a complex mixture of organic and inorganic compounds. Water forms by far the greater part of the protoplasm. In it are dissolved proteins, carbohydrates and lipides, and traces of inorganic salts and gases. The concentration of the different constituents is very variable as substances are being absorbed into or passed out of the protoplasm all the time, and the organic compounds are continually being destroyed and re-formed by chemical reactions. Many of these organic substances have relatively large molecules which tend to clump together when in solution, forming a very fine suspension in the liquid medium. Such substances are known as colloids and give the solution a slightly gelatinous consistency. Because of its colloidal nature protoplasm has many valuable properties: it is elastic and pliant and so not easily injured by deforming forces, its semifluidity allows movement within itself so that its contents are constantly brought into intimate contact, while speedy and extensive chemical reactions between them are favoured by the immense surface area presented by the minute solid particles in suspension in the water.

STRUCTURE OF A TYPICAL ANIMAL CELL

A single-celled animal, such as the amœba, shows all the characteristic manifestations of life in their most elementary form, and its structure exemplifies the basic structure of all animal cells however greatly differentiated they may have become.

This typical animal cell has no distinct or constant form since, unlike a plant cell, it has no definite cell wall.

The only boundary is an elastic membrane which is formed at the surface of the protoplasm by some of its lipide and protein constituents. This surface is semi-permeable and acts as an absorbing membrane, allowing the passage through it of certain substances, mainly in solution.

In the centre of the cell is a denser mass of protoplasm, the nucleus. This is the controlling centre without which

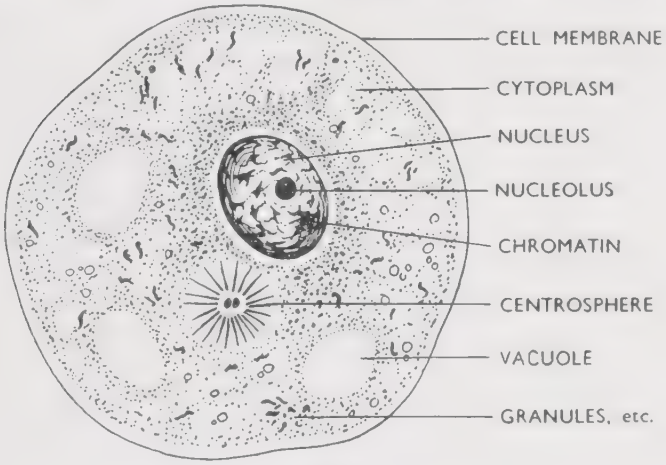


Fig. 1
DIAGRAM OF A TYPICAL ANIMAL CELL

the cell would be unable to reproduce, its activities would cease and it would rapidly die. The protoplasm of the nucleus is termed the nucleoplasm, as distinct from that of the rest of the cell which is called the cytoplasm.

The cytoplasm generally appears opaque as it contains drops and granules of other substances included in the cell. These may be "fuel" materials such as glycogen or fat which are being stored, or food particles which have recently been absorbed into the cell. Other substances such as specially synthesized secretions, as well as waste

materials which have been formed by cell activity, are often present in the cell prior to their being passed out through the membrane. They may be in granular form, or in solution in vacuoles. In some cells the cytoplasm is coloured by pigments: these are natural colouring materials and must be distinguished from artificial stains.

Specialized parts of the living cytoplasm connected with certain of the cell functions include minute rods and threads called mitochondria which are scattered throughout the cytoplasm, and the Golgi apparatus, a network of fibrils surrounding or lying close to the nucleus. Both these structures probably are formed of lipo-proteins. They are apparently the seat of various chemical reactions, especially those associated with cell respiration and the formation of secretions. The centrosome or centrosphere is a clear area of cytoplasm surrounded by radiating threads also lying close to the nucleus. It contains one or two darkly staining bodies, the centrioles, which participate in cell division.

The nucleoplasm is separated from the cytoplasm by a fine nuclear membrane. The nucleus contains an oval body, the nucleolus. The greater part of the nucleus is formed of a readily stainable protein called chromatin. When a cell divides the chromatin becomes concentrated on minute threads or rods of nucleoplasm to form chromosomes. These structures are the carriers of inheritable characteristics. When the cell is not dividing the chromatin is scattered throughout the nucleus, and the rod-like structures, although present, cannot be demonstrated by staining.

The number of chromosomes which form when a cell divides varies in different animals, but is constant for all the cells of any one species. The sex cells have half this specific number. In the human body the characteristic number is forty-eight and the chromosomes are arranged

in pairs. This number is maintained by a special method of splitting when a cell divides. The human sex cells contain twenty-four chromosomes arranged singly.

PHYSIOLOGICAL ACTIVITIES OF ANIMAL CELLS

Metabolism

The cytoplasm is the storehouse and the workshop of the cell and is the site of numerous chemical reactions. All these reactions are collectively termed metabolism, but can be divided into two main types, which are both antagonistic and complementary to each other. Reactions by which complex substances with large molecules and a high energy content are synthesized from simpler substances are called anabolic processes, or collectively, anabolism. These are "building up" reactions and involve the use of energy to form and hold together the large molecules. The materials for these reactions are selected and absorbed by the cell from its surroundings, while the energy is supplied by the other type of metabolic process, known as katabolism. Katabolic processes are destructive. In them previously formed substances of large molecular structure are broken down to small simple molecules with a low energy content, the surplus energy being set free. The katabolic processes which liberate the greatest amount of energy are of the oxidative or aerobic type. Oxygen is taken into the cell from outside and is used to oxidize "fuel" substances in the protoplasm, forming carbon dioxide and water and setting free energy. Other katabolic processes which occur without the use of oxygen are termed anaerobic. In them the breakdown cannot be taken very far, so that comparatively small amounts of energy are set free and the end products are still fairly complex.

The greater part of the energy liberated during katabolism appears in the form of heat. Of the remainder a

variable amount of energy is utilized by the protoplasm in its anabolic processes for the repair of cell material and for other building reactions, such as the formation of secretions. Energy is used also in the production of movement, in the conduction of nerve impulses and in cell division.

The balance between anabolism and katabolism is not exactly maintained. In favourable conditions a resting cell will accumulate material and increase in size, due to the greater speed of the anabolic processes; while during activity, when katabolism proceeds more rapidly, the cell substance tends to become depleted.

Metabolic processes are responsible for all the characteristic signs of life, whether the organism is a simple unicellular animal like the amœba, or a complex multicellular structure such as man. The intake of oxygen and food, the output of carbon dioxide and other excretions, the ability to grow, to reproduce, to form and utilize energy and to adapt to changing external conditions, are all physiological functions essential to life and indicative of the chemical reactions taking place in the protoplasm of the cells.

The Intake of Oxygen

Although a certain amount of energy is set free by anaerobic katabolism this is insufficient for all the cell's requirements. The rebuilding of the cell's stores and protoplasm could not take place without the large amount of energy liberated by oxidative processes. For this reason all cells must take in oxygen from their surroundings. During combustion, that is the burning of fuel in the presence of oxygen, carbon dioxide and water are formed as waste products and are then passed out of the cell. The gaseous exchange through the cell membrane of oxygen from outside with the carbon dioxide formed within the cell is called respiration.

The Intake of Food

Cells require raw materials for many of their anabolic processes. Comparatively simple "foods" are absorbed through the surface membrane into the cell body from the surrounding medium. Inside the cell these substances are synthesized into the various constituents of the protoplasm to repair loss or to produce growth. Proteins, "fuel" stores for subsequent katabolism and energy liberation, pigments and secretions may all be formed. In all cases the materials synthesized will be similar to those already in the cell, and may, as in the case of proteins, be peculiar to the particular type of cell. The anabolic processes by which "food" is transformed by a cell into its own substance are known as assimilation.

Excretion

During metabolism various substances are formed which are of no further use to the cell, and which would poison the cell and inhibit its functions if they were allowed to accumulate. These waste or excretory products are formed mainly by katabolism, though some may be by-products of anabolic processes. Their removal from the cell is known as excretion. Some excretory products may be of a moderately complex nature, while the simplest are carbon dioxide and water, the result of complete oxidation.

Secretion

Some substances are formed specifically to serve a useful purpose when discharged from the cell. These are known as secretory products. Their formation by anabolism and their passage out of the cell constitute the process of secretion.

Movement

Movement may occur in the whole or in part of a cell.

When an amœba travels (by means of pseudopodia) there is continual change in the shape of the cell and a flowing of the cytoplasm. In the human body the white cells of the blood exhibit a similar form of movement.

The movement of a muscle cell is termed contraction. This implies not a diminution in size, but a shortening in one direction with a corresponding increase in the thickness of the cell.

Some cells have minute protoplasmic processes, called cilia, which project from their surfaces like tiny hairs. Each cilium exhibits a lashing movement during which it

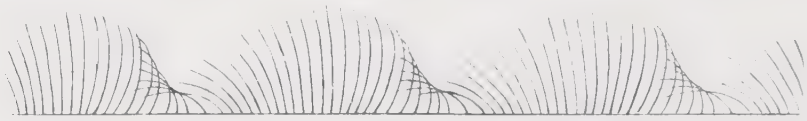


Fig. 2

DIAGRAM SHOWING CILIARY MOVEMENT PASSING IN WAVES OVER A CILIATED SURFACE

swings over as an almost rigid rod in one direction and recoils limply in the opposite direction. A ciliated surface is in continual rhythmic motion, like a field of corn swept by the wind, the phases of ciliary movement passing across it in rapid waves. Such a surface acts as a "conveyer belt" for any particles that come into contact with it.

Continual movement of the protoplasm within the cell membrane occurs in all cells. The protoplasm gradually streams round so that all its constituents are thoroughly mixed and brought into contact with each other. At times more organized movements of definite parts of the cell contents occur, such as the reorganization of nuclear material which takes place in the first stages of cell division, and which is followed by movement of the cytoplasm when the cell splits into two. Kinetic energy is responsible for all these different forms of movement.

Conduction

Energy also is used when an impulse or "message" is conveyed from one part of a cell to another. This does not involve the movement of matter but is a sequence of chemical and energy changes through the protoplasm, comparable to the firing of a train of dynamite. All cells are capable of some degree of such conduction but nerve cells specialize in this function.

Reproduction

Life does not arise spontaneously. New living cells or organisms are formed from previously existing ones. The essential process in all reproduction of new life is the splitting or fission of part of the protoplasm, including both nucleoplasm and cytoplasm, from the "parent" cell or animal.

In cell division a series of changes takes place during which there is a rearrangement of nuclear material followed by division of the nucleus and subsequent division of the whole cell. The most important structures participating in these changes are the chromosomes. These threads carry minute particles of chromatin called genes, arranged along the length of the chromosome. The genes represent the inheritable characteristics. To ensure that each "daughter" cell shall receive an equal inheritance longitudinal division of the chromosomes must occur. In this way the daughter cells each receive equal portions of the same genes, and a qualitative as well as a quantitative division of chromatin material is effected. This type of cell division is known as mitosis. The changes, which are always preceded by growth of the existing cell, may be summarized as follows:—

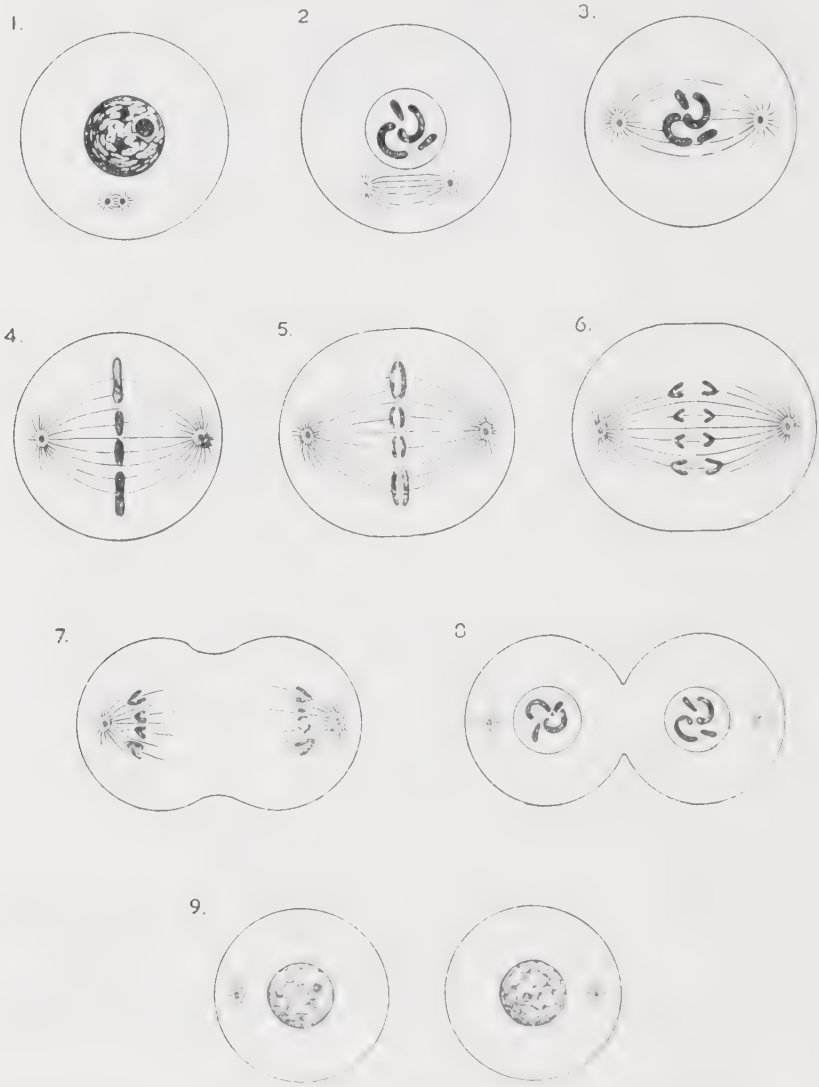


Fig. 3

DIAGRAM SHOWING THE CHANGES WHICH OCCUR IN THE NUCLEUS AND CENTROSOME OF A CELL DURING MITOSIS

The nucleus is shown containing four chromosomes only.
The figures refer to the description in the text.

* 1. There is an increase of chromatin material in the nucleus. In stained preparations this makes the nuclei appear very dark. The centriole (if single) divides into two. The two centrioles now move away from each other, and as they do so they appear to draw out the surrounding cytoplasmic rays into a spindle of fine threads.

2. The nucleolus disappears. The chromatin becomes concentrated to form the chromosomes, which can now be demonstrated by staining.

3. The nuclear membrane disappears. All the nuclear material is now in the form of chromosomes which lie freely in the cytoplasm. The fine unstainable threads between the centrioles now stretch across the whole cell forming the achromatic spindle.

4. The chromosomes become arranged around the equator of the spindle and appear to be actually attached to the threads.

5. The chromosomes begin to divide down their length. The two halves separate at first at the centre then down their whole length.

6. The half chromosomes, or chromatids, move away from each other to opposite poles of the cell.

7. A constriction appears round the centre of the cell body. Equal numbers of chromatids, corresponding to the original number of chromosomes, lie grouped at either end of the cell.

8. A nuclear membrane forms round each group of chromatids. The constriction in the cytoplasm increases.

9. A typical nucleus re-forms round each group of cytoplasm. The chromatin is redistributed throughout the nucleoplasm and the nucleolus reappears. Final division of the cytoplasm occurs forming two separate cells exactly similar in their structure and in inheritance to the original cell.

* The numbers correspond to the figures on the accompanying diagram (Fig. 3).

The whole process of cell division takes from one half to six hours.

A single-celled animal such as an amœba is able to reproduce itself by division in this way. In multicellular animals such a simple method of reproduction is not possible. In practically all such animals special cells are developed to carry out reproduction. An exchange or fusion of these cells between two members of the same species almost always takes place. In the more primitive animals the participating individuals and cells may be in no way different from each other. In the higher animals, including human beings, reproductive cells of two distinct types are formed in individuals of separate sexes. By fertilization, that is the fusion of a female sex cell with a male sex cell, a single cell is formed from which the new individual, consisting of millions of cells, will develop by repeated mitosis.

Since the single cell from which the whole body will develop must contain the number of chromosomes characteristic of the species, it is obvious that the sex cells must each contain half this number. During the formation of the sex cells in the male and in the female body a special type of cell division takes place by which the chromosome number is halved. This is known as reduction division or meiosis. The changes occurring in the nucleus and cytoplasm are similar to those in mitotic division up to the stage when the chromosomes are arranged round the equator of the spindle. In meiosis whole chromosomes, one from each pair, pass to opposite ends of the cell, so that when the cell divides the daughter nuclei each contain half the original number of chromosomes.

Automatism

Unlike machines, living organisms are capable of carrying out their activities without outside assistance. A watch requires periodic winding, an internal combustion engine

needs refuelling, decarbonizing and oiling, but a living cell or organism can do the equivalent of these functions for itself. Providing the surrounding conditions are favourable and sufficient food and oxygen are obtainable the individual cell processes will take place automatically. This ability to act independently is known as automatism.

Irritability

The cell activities are, however, considerably influenced by external factors. Cells are very sensitive to alterations in their immediate environment, and will react in various ways. A change which will produce a response is known as a stimulus, and the ability of living matter to respond to a stimulus is known as irritability. The response will vary according to the type of stimulus and the particular properties of the reacting cell. Some cells are more irritable than others, and certain cells will respond to one type of stimulus only. A stimulus may be of a physical nature such as heat, light, stretching or pressure. Cells may respond to alterations in the acidity or alkalinity of their surrounding medium, or to specific chemical substances. In some cases cells may be stimulated by the activity of other cells, as for example the contraction of a muscle cell which occurs in response to a nervous impulse.

DIFFERENTIATION OF ANIMAL CELLS

In organisms such as the amœba all the activities of life are the duty of the single cell mass, which is therefore capable of an independent existence. Certain other unicellular animals live in groups or colonies. In these each of the similarly constructed members continues to live its own individual life, unaffected by the activities of those around it. Such colonies of undifferentiated members are small and comparatively rare. On the other hand, multicellular organisms, in which the cells co-operate for the

well-being of the body as a whole, are very common. In these, different groups of cells undertake and specialize in the performance of particular functions.

In assuming a specialized function a cell may lose, partly or entirely, the ability to perform some of the other activities. All cells absorb and assimilate food, take in oxygen for oxidative processes and form waste products which they excrete; but glandular secreting cells cannot contract, muscle cells form no secretions and fully developed nerve cells have lost the power of reproduction.

Specialized cells generally show modifications of their structure which allow for the most efficient performance of their activities. These adaptations are most obvious in the different shapes of various specialized cells. For example, in nerve cells the cytoplasm is pulled out into extremely long fine processes, which branch at the extremities. This shape enables a nerve cell to transmit an impulse for a greater distance, and by its many branches contact many more cells than would be possible if it were more compact in form. In order to get the maximum movement resulting from contraction, the cells of skeletal muscle (the muscle that moves the bones) are shaped like very long thin cylinders. When these contract, the shortening takes place in the long axis with corresponding thickening of the cell.

Variations in the arrangement of the cell contents often accompany an adaptation in shape. In the muscle cells described above, the nuclei, which are numerous, lie just beneath the cell membrane where, presumably, they do not interfere with the movement of the cytoplasm during contraction. In other cases variation or rearrangement of cell contents may be the more marked feature of the modified structure. Secreting cells often have their nuclei displaced to the base of the cell so that there is an uninterrupted mass of cytoplasm adjacent to the free surface, where the secretion can be formed and stored. Some cells store fat which can be drawn upon by more active cells to

be used as fuel. The appearance of a fat cell varies according to the amount of fat it contains. It is originally an undifferentiated cell, but the gradual accumulation of fat droplets within it displaces the protoplasm until, in its most distended form, the greater part of the cell is taken up by a single drop of fat; while the cytoplasm, containing the nucleus, forms a thin membrane round the outside.

Many other examples of specialized cells and their adaptation to function will be met with in the study of the individual tissues.

THE ORGANIZATION OF TISSUES

Cells of all different varieties are not mixed together in the body in a haphazard way, but are arranged according to their embryonic origin and their function into separate tissues. In most cases the cells of a tissue are held together by a certain amount of intercellular substance. The physiological and physical properties of the tissue as a whole are determined by the arrangement and the properties of both the constituent cells and the intercellular substance.

In secreting tissues and in muscles for instance, the cells are the important functional units and form the bulk of the tissue; while the amount of intercellular substance is insignificant, serving only as retaining material between the cells. The efficiency of these tissues is largely dependent on the arrangement of the cells. For example, in skeletal muscle, the cells are arranged parallel to each other in bundles or sheets, and movement is produced by the summation of the individual cell contractions.

In certain tissues the intercellular substance predominates and greatly influences the properties of the whole tissue. Tissues of this type are concerned mainly with the mechanics of the body architecture rather than with its physiological activities. The intercellular substance

may be strong and rigid as in bone, or firm but resilient as in cartilage (gristle). In some tissues it is elastic and extensible; while in others it is pliable but allows of no stretching.

A good example of the co-operation between cells and intercellular substance is afforded by the blood. Blood depends on its fluid plasma, which is the intercellular substance, for its ability to circulate through the heart and blood vessels. The plasma acts also as a solvent for many substances, and is capable of penetrating through the capillary walls into the tissues. In addition, the plasma conveys the various kinds of blood cells, which have their own independent functions.

The tissues of the body work in conjunction with one another, and are arranged according to their functions into structures, such as the heart, liver, stomach and lungs, which are called organs. Each organ has a definite form and position in the body.

Several organs are correlated to form a system, which carries out one or other of the main functions of the body. The functions of the systems are comparable with the simple activities exhibited by a single-celled animal. They are regulated by other controlling systems. In this way each can adapt to the others and to the general needs of the body. To consider any of these systems as independent mechanisms is to lose sight of the functional integrity of the body as a whole.

CHAPTER II

THE PREPARATION OF TISSUES

A brief outline of the chief processes involved in preparing animal tissues for examination under the microscope.

THE tissues may be examined under the microscope in their fresh condition, but in most cases a certain amount of preparation is necessary to prevent degeneration and to render the different parts more distinct. Prepared specimens differ considerably in their appearance from the fresh tissues. These notes are intended to help the student, with little or no knowledge of histological methods, to understand the main changes which are brought about in the tissues by the various processes involved in their preparation. Each tissue has its own peculiarities regarding preparation and staining. A few only of the more usual methods of making permanent preparations are outlined here. For details of histological technique the student should consult a standard textbook of histology.

Fixation

To prevent degeneration, the tissue should be treated, as soon after death as possible, with reagents known as fixatives. The fixative solution diffuses rapidly through the tissue, causing changes in the nature of the proteins. Its purpose is to kill the protoplasm while preserving, as far as possible, the lifetime appearance of the cells. It also prevents decomposition by destroying the autolytic enzymes. Fixation often causes slight shrinkage of the protoplasm, so that spaces appear in the tissue. It may also produce granules or fibrils where they are not normally present. Such changes in appearance which

occur after the death of the tissue are known as artefacts. Some fixatives are fat solvents which, while preserving the greater part of the tissue, remove the fat.

Some tissues may be fixed by evaporation. For instance, a film of blood on a glass slide may be left in the air to dry, or passed through a flame, rapidly evaporating the plasma and fixing the solid structures.

Section Cutting

The specimen of tissue to be examined must be sufficiently thin to allow light to pass easily through it. The tissue may be cut into thin shavings, or be teased or spread out on a glass slide.

Fine shavings or sections, each approximately one cell in thickness, are cut by a mechanical razor known as a microtome. The softer tissues must first be hardened, either by freezing in a suitable supporting medium, or by embedding them in a material, such as paraffin wax, which itself will solidify. The supporting or embedding material is dissolved out of the tissue after the section is cut: when a fat solvent is used for this purpose it also removes any fat present in the tissue itself.

Sections of hard tissue, such as bone, can be made if the inorganic salts are first removed by the action of dilute mineral acids, a process called decalcification: or the calcified tissue can be ground on a lathe until the requisite thinness is attained. This latter method destroys all the more fragile protoplasmic structures in the tissue, and the cell spaces become filled with bone dust.

As the section passes through one plane of the tissue or organ, certain cells and other three-dimensional structures are seen in part only, or not at all. This gives the section a somewhat different appearance from a diagram of the same structure.

Some tissues lend themselves to other methods of preparation. Blood, for instance, can be drawn out into a fine

film on a slide by using a second slide held at an angle; while areolar tissue, mesenteric tissue and certain other tissues can be stretched out into thin expansions. The individual cells or fibres of some tissues may be seen more easily if they are teased apart with needles. This method is often used to separate the fibres of muscles, of nerves and of the connective tissues. It has the disadvantages of sometimes tearing the cells or fibres, and of disturbing their normal relationship to each other.

Staining

By means of staining, various parts of the cells or tissues may be more easily differentiated. Most stains will diffuse throughout the tissue, colouring more deeply those parts which have a greater affinity for the stain. Some stains are taken up by one constituent of the tissue only.

The cell nuclei stain heavily and so stand out from the surrounding cytoplasm. Also they may be coloured differently from the cytoplasm since the nuclear material has an affinity for alkaline stains, such as methylene blue or hæmatoxylin (blue), while the cytoplasm stains more readily with acid dyes, such as eosin (pink). Further, in the cytoplasm itself, certain constituents can be demonstrated by staining; this, in some cases, serves to differentiate between various cells, as for example the granulocytes of the blood.

If a fat solvent is used at any stage in the preparation of the tissue, all the fat is removed, leaving empty spaces to mark its original position; but if the tissue is prepared in such a way that the fat is retained, it can be coloured by suitable stains.

The intercellular material may be shown up as distinct from the cells by using reagents which will react with it chemically. In such preparations the cells, unless coloured by other stains, will appear as clear spaces. This method of staining is of value in demonstrating the shapes of the

cells which, owing to their exceedingly fine membranes, cannot always be seen clearly. Specific stains are used to distinguish between the various fibres of the connective tissues and the matrix.

Some cells will readily take up specific stains during life if the stain is introduced into the blood stream. This is known as vital staining. The distribution of the stain can be studied from tissue preparations made after death. Cells of the reticulo-endothelial system can be demonstrated in this way.

The arrangement of the blood vessels in a tissue or organ can be demonstrated by filling them with some suitable colouring material. This is introduced into one of the main vessels supplying the part before the tissues are fixed and the sections are cut. In the sections made from injected tissue the vessels stand out as distinct from the surrounding structures. Lymph vessels and ducts of glands may be similarly injected.

Mounting

The specimen is finally mounted on a glass slide in a drop of Canada balsam and protected by a fine glass coverslip. The Canada balsam gradually hardens, causing the coverslip to adhere firmly to the slide. Glycerine is sometimes used for mounting.

CHAPTER III

THE SURFACE AND LINING TISSUES

The epithelial, mesothelial and endothelial tissues—their general characteristics, structural types and functions.

GENERAL CHARACTERISTICS

THE surface and lining tissues fall into three groups, epithelium, mesothelium and endothelium. The epithelial tissues cover all external parts of the body and, in addition, line the organs and passages of the digestive, respiratory, urinary and genital systems, down to their smallest ramifications. The pleural, pericardial and abdominal cavities are similarly lined; but the tissue in these positions is sometimes referred to as mesothelium. Certain other closed cavities and systems, including the circulatory system, are lined by endothelium. This is a lining formed of connective tissue cells, and in respect of its embryonic origin it should be classed as a modified connective tissue: yet on account of its similarity, both in structure and function, to certain of the epithelial tissues it is included in this chapter.

All these surface and lining tissues are essentially cellular in structure. The cells are comparatively small, containing usually a single spherical or ovoid nucleus. The cells are arranged in layers, the depth of the tissue depending on the thickness of the cells and the number of layers present. Simple tissues are formed of a single layer of cells only, while in compound tissues there are two or more layers. The cells are fairly regular in outline and, in any one layer, are uniform in size and shape, but in compound tissues there is generally some variation from layer to layer. The cells of the topmost layer present a very

smooth surface. This surface is sometimes ciliated, or it may be covered by a non-protoplasmic cuticle formed by modifications of the superficial parts of the surface cells, or by secretions from them. With the exception of the epidermis of the skin, the free surfaces of all epithelial tissues are moist and slippery.

The cells reproduce by mitosis for maintenance or growth of the tissue, and for replacement after injury. In the compound tissues it is the deepest cells which form the growing layer and replace cells as they are worn away from the surface.

The intercellular substance is insignificant in amount, serving only as a retaining material between adjacent cells and cell layers. This material is not continuous; there are small communicating spaces in it forming a system of intercellular channels. In some cases protoplasmic threads stretch across these spaces joining neighbouring cells.

In the majority of tissues a film-like expansion of retaining substance, the basement membrane, underlies the basal surface. It attaches the epithelium to the connective tissue below and supports the cells in contact with it. In some positions this membrane is deficient.

The epithelial tissues are pliant, soft and elastic. These qualities are less marked in certain tissues where the surface cells become somewhat hardened.

Epithelial tissues are avascular, that is to say they contain no intercellular blood vessels. The cells derive their nutriment and oxygen from the tissue fluid which filters through from the capillaries in the underlying connective tissue. The fluid soaks through the basement membrane into the intercellular spaces and bathes the cells.

Most epithelial tissues contain some receptor (sensory) nerve endings, from which nerve impulses pass by afferent fibres to the central nervous system. The type of nerve ending varies with the position and character of the tissue. Some of the more active tissues also receive nerve fibres (efferent), by which their activities are regulated.

STRUCTURAL TYPES OF EPITHELIAL TISSUES

The Simple Tissues

1. *Squamous, Pavement or Flattened Epithelium*

This tissue is composed of a single layer of extremely thin cells with correspondingly flattened nuclei. The cells fit closely together at their edges, forming a continuous smooth surface.

Simple squamous epithelium forms parts of the kidney tubules (Bowman's capsule and the thin segment of the loop of Henle). It lines the tympanic cavities and the membranous labyrinth of the ear, the tubules of the rete testis, and the smallest ducts of some glands, *e.g.* pancreas. The simple squamous epithelium lining the alveoli of the lungs is thought, by some histologists, to be very incomplete; while others deny its existence.

Mesothelium

The simple squamous epithelium which lines the serous cavities of the body in the form of the pleura, the pericardium or the peritoneum, is sometimes called mesothelium. This tissue covers also the external surface of most of the organs contained in these cavities.

Endothelium

Endothelium is similar in structure to simple squamous epithelium, being formed of flattened cells. There is, however, no basement membrane. The cells are derived from undifferentiated connective tissue cells, and are closely related to those cells (phagocytes) which are capable of the ingestion of foreign materials and bacteria.

Endothelium lines the heart, the blood vessels and the lymphatic vessels, the anterior chamber of the eye, the perilymphatic spaces of the inner ear, and the subarachnoid and subdural spaces of the central nervous system.

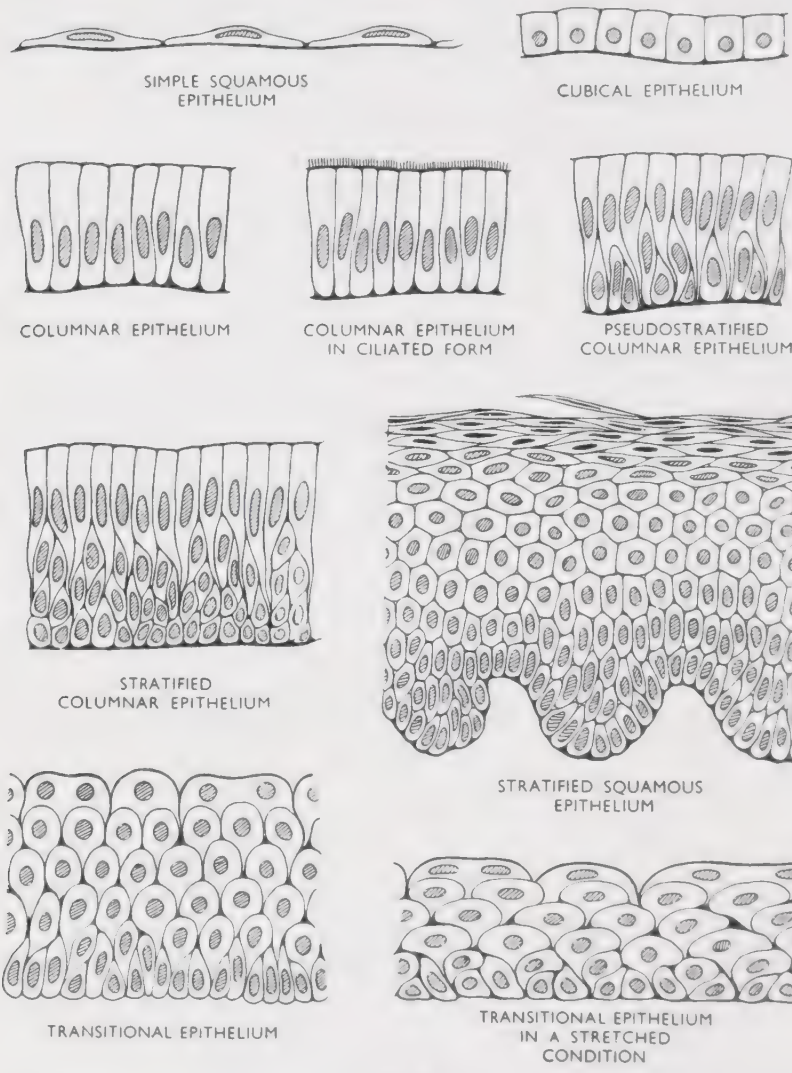


Fig. 4

DIAGRAM OF THE DIFFERENT STRUCTURAL TYPES OF EPITHELIAL TISSUES

Each tissue is shown in vertical section.

It also lines the joint cavities and the bursæ. These latter are clefts within connective tissue which develop as the result of constant movement. In certain positions the endothelial membrane is very incomplete, here the cells may retain the function of phagocytosis.

2. *Cubical Epithelium*

This is a layer of cubical or short prismatic cells which have a square appearance in vertical section. The nuclei are generally spherical.

Cubical epithelium forms the secreting tissue of many glands, as well as lining their ducts. It forms the thyroid vesicles, parts of the kidney tubules and the pigmented layer of the retina of the eye. It covers the choroid plexuses of the central nervous system and forms the germinal covering of the ovaries.

3. *Columnar Epithelium*

This tissue is formed of longer prismatic cells appearing rectangular in vertical section, though they often tend to taper towards their bases.

It lines the alimentary canal from the stomach to the anus, and forms the ducts and secreting tissue of certain glands. It also lines the gall bladder and bile ducts.

Ciliated columnar epithelium lines the smaller bronchioles. In the lining of the Fallopian tubes ciliated cells are interspersed between non-ciliated cells. The columnar cells that line the vasa efferentia, the epididymis, the ventricles of the brain and the central canal of the spinal cord have non-motile cilia.

4. *Pseudostratified Columnar Epithelium*

This tissue consists of a superficial layer of columnar cells which form the free surface; their long tapering roots

extend down to the basement membrane. Small polyhedral cells fit between the roots of the surface cells. All the cells are in contact with the basement membrane.

It lines parts of the Eustachian tube, the male urethra and vas deferens.

Ciliated pseudostratified epithelium lines parts of the pharynx and larynx, the trachea, the bronchi and the larger bronchioles.

The Compound Tissues

1. *Stratified Columnar Epithelium*

In this tissue a surface layer of columnar cells rests on several layers of small polyhedral cells.

It forms the conjunctiva of the eyelid, and lines part of the male urethra and the main ducts of certain large glands, *e.g.* salivary glands.

In ciliated form it lines the respiratory parts of the nasal passages, the nasal sinuses and the naso-pharynx.

2. *Transitional Epithelium*

This tissue contains several layers of loosely packed cells. The deepest are small cubical or short columnar in shape; the intermediate cells are pear-shaped, and the upper cells are umbrella-shaped, with their projections fitting between the cells of the deeper layers. A non-protoplasmic cuticle is present on the surface of these upper cells, some of which may contain two nuclei. The whole tissue is soft and pliable, and is very easily stretched. It is peculiar in having a very incomplete basement membrane.

It lines the pelvis of the kidney, the ureter, the urinary bladder and the upper part of the urethra.

3. *Stratified Squamous Epithelium*

This is the thickest of all the epithelial tissues, consisting of many layers of cells. The deepest layers are composed

of columnar cells; the intermediate layers of polyhedral cells, and the upper layers of squamous cells. On account of the depth of the tissue the superficial layers are dead, since the cells become increasingly separated from the source of the tissue fluid as they near the surface. These dead cells are continually being replaced by division of the deep cells.

Stratified squamous epithelium forms the epidermis of the skin and the surface tissue of the external genital organs. It covers the cornea of the eye and forms the adjacent conjunctiva of the eyeball. It lines the external auditory meatus, the lower parts of the nostrils, the tear ducts, and the mouth cavity where it also covers the tongue. It lines the œsophagus, parts of the pharynx and larynx, the anal canal, the lower parts of the male and female urethra and the vagina.

Massed Epithelial Cells

In the development of the body the proliferation of certain epithelial tissues leads to the formation of cellular masses in which the surface arrangement of the cells has been partly or entirely lost. The liver and the adrenal glands are examples of organs composed largely of massed epithelial cells.

FUNCTIONS OF THE SURFACE AND LINING TISSUES

The surface and linings of the body fulfil many functions and are adapted accordingly. Some tissues have more than one function.

I. Protection

Epithelial tissues act as limiting layers throughout the body and help to prevent bacteria and other foreign materials from penetrating into the deeper and more

vulnerable parts. Some tissues are more specially adapted for such protection than others.

Mechanical protection is best afforded by the compound tissues in virtue of their thickness and their ability to replace damaged or lost surface cells by division of cells in their lower layers. Stratified epithelium is an excellent example of such a tissue. It constitutes the epidermis of the skin and therefore covers the whole exterior of the body. In the more exposed parts a greater thickness is given by many more layers of dead squamous cells on the surface. In addition, these surface cells develop within their protoplasm a protein, keratin, which hardens the cells making them tough and scaly, and greatly enhances the protective value of this superficial layer. Keratinization (cornification) and an increase in thickness are very marked on the palms of the hands and the soles of the feet, but are also features of any part of the epidermis which is exposed to continual friction. The finger and toe nails and the hairs are special outgrowths of the epidermis which are heavily keratinized.

Stratified epithelium in a less thickened, non-keratinized form lines the beginnings of all passages into the body. Its inward extent in the different passages is determined by the amount of friction to which each is subject.

In spite of the dead and keratinized surface cells, stratified epithelium is, on the whole, a fairly pliable and elastic tissue. Its ability to "give" under pressure saves it from being easily ruptured.

In some parts of the body, such as in the lining of the urinary bladder, a greater extensibility and elasticity is required than is allowed by stratified epithelium. Here the transitional epithelium offers the advantages of a compound tissue combined with extreme elasticity and pliability. As the bladder becomes distended the whole tissue is stretched, the cells of all layers becoming broader and more flattened. When the bladder is emptied the

tissue recoils and the cells return to their more elongated shapes. The lack of a basement membrane possibly increases these mobile qualities. The cuticle developed by the surface cells protects the tissue from the acidity of the urine.

Some epithelial cells contain substances which are protective. Keratin has already been mentioned; another example is a pigment melanin, contained in the deep cells of the epidermis. This material absorbs the harmful light rays and in this way prevents them from penetrating through to the underlying structures. The action of the light rays is to increase the amount of pigment and alter its distribution: this produces tanning of the skin.

The sensory properties of the epithelia, the ability of certain of these tissues to remove substances from their surface by ciliary movement, and the production of protective secretions are all further protective adaptations which will be considered in the sections on sensory functions, ciliary movement and secretion respectively.

2. Reduction of Friction

Some internal surfaces, not open to violent trauma, are yet subjected to continual slight friction, due either to fluid flow or to movement of adjacent surfaces. To minimize such friction, smoothness of the lining tissue is of great importance. The very fine layer of endothelial cells which lines the entire circulatory system offers the least possible resistance to the blood flow.

The pleural, peritoneal and pericardial cavities are lined by pavement epithelium (mesothelium) which is reflected also on to the contained organs. The two surfaces are separated only by a fine film of lymph-like fluid which filters through the membrane. The extreme smoothness of the tissue and the presence of the fluid allows an easy gliding movement between adjacent organs, and between the organs and the lining of the cavity.

A comparable arrangement is found in joint cavities and in the bursæ between muscles or tendons and bone. In these spaces the endothelial lining is somewhat incomplete, but it is so moistened by fluid, here called synovial fluid, that movements of joints are facilitated, and friction produced by the gliding of tendons and muscles is practically eliminated.

3. Membranes for Diffusion, Filtration and Osmosis

The passage of substances through an animal membrane may be effected by the purely physical processes of diffusion, filtration or osmosis. In the body these physical methods are often the means by which substances pass between the external surroundings of the body and the body fluids, between the blood and the tissue fluid, and between the tissue fluid and the cells.

A membrane formed of a single layer of flattened epithelial or endothelial cells has a certain degree of permeability. Such membranes usually allow the passage of water and most crystalline substances in solution, but colloids such as proteins can pass through less readily, or not at all. Carbon dioxide, heat and trauma increase the permeability of animal membranes.

An example of diffusion is the exchange of oxygen and carbon dioxide through the respiratory membrane of the lungs. To present the greatest possible area for diffusion in the space available, the respiratory surface is arranged as minutely convoluted compound sacs at the terminal branches of the respiratory passages, the smallest hemispherical compartments being called alveoli. The walls of these alveoli are exceedingly thin and are formed of delicate connective tissue which supports a dense network of capillary vessels, one set of capillaries serving two adjacent alveoli. It is thought that the simple squamous epithelial lining to the alveoli is very incomplete, so that the capillary vessels are, in most places, in direct contact

with the air on either side. The endothelium of the capillary walls, being formed of very flattened cells, offers the least possible resistance to the diffusing gases. The whole tissue is very delicate and yields easily with the movements of the lungs during inspiration and expiration.

In other parts of the body the walls of the capillary vessels allow the outward filtration of water and certain dissolved substances from the plasma of the blood into the tissue spaces. This filtrate forms the tissue fluid which bathes all the cells, providing them with their materials for metabolism and receiving their waste products. All exchange of materials in solution between the blood and the tissue fluid is effected by diffusion, which takes place with great rapidity owing to the thinness and permeability of the capillary walls. The passage of water from the tissues back into the blood is, however, brought about by osmosis. This occurs at the venous end of the capillaries due to the concentration of proteins in the blood plasma being greater than in the tissue fluid.

Filtration through a double membrane occurs in the kidneys, where isolated tufts of capillaries (glomeruli) are surrounded by the invaginated, blind ends of the kidney tubules (Bowman's capsules). This capsule is formed of squamous epithelium. Fluid filtered from the glomerular capillaries passes almost immediately through the internal layer of the capsule into the tubule. Before being passed from the kidney as urine the fluid flows through subsequent parts of the tubule, where absorption of useful substances and additions of further excretory products occur. The presence of fluid in the serous cavities, in joint cavities and in bursæ is due also to filtration through their lining tissue.

4. Secretion

The process of secretion involves activity on the part of the epithelial cells, including the absorption of raw materials

selected from the blood, the synthesis of the secretory product in the cytoplasm of the cell, where it may be temporarily stored, and finally the extrusion of the secretion from the cell.

Secreting surfaces are generally formed of simple cubical or columnar epithelium, though pseudostratified or stratified columnar epithelium is found where greater protective properties are required. In some tissues, where the secretory product is formed and stored in the upper part of the cell, the nucleus is displaced to the base. In many secreting tissues the basement membrane is incomplete and this allows absorption from the tissue fluid to take place more quickly and easily. A rich blood supply in close contact with the basal surface of the tissue is essential. Nerve fibres are distributed to both the blood vessels and the secreting cells.

Secreting epithelium lines many organs: in most cases the secreting area is increased by invagination forming structures known as externally secreting or exocrine glands. Exocrine glands vary in their shape and complexity, the simplest being the single tubular structures in the intestines. The secreting tissue of the more complex glands is so highly invaginated that the secretion has to travel through tubes or ducts to reach the original surface. These ducts are lined also with epithelium which may or may not be secreting. The structural types of exocrine glands are shown diagrammatically.

The functions of exocrine secretions fall under the three main headings of catalysis, protection and excretion. Secretions performing catalytic functions do so in virtue of the enzymes they contain. Enzymes are organic compounds which bring about or hasten specific chemical reactions without any change to themselves. Those produced by externally secreting glands are concerned mainly with the digestive changes, and are secreted on to the food in the mouth and in its course along the alimentary canal.

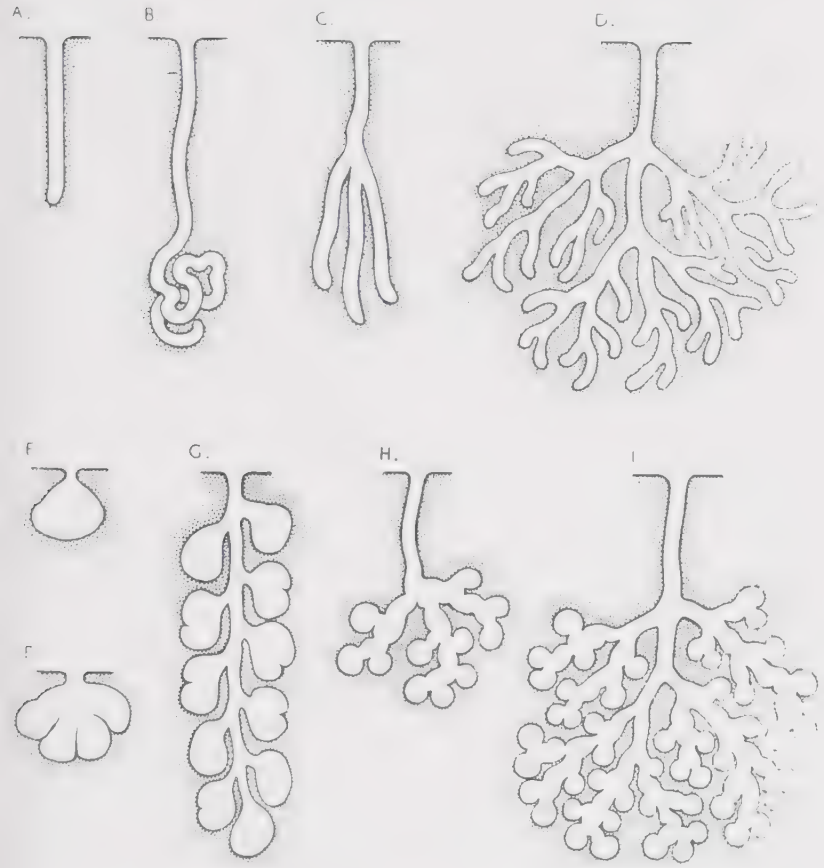


Fig. 5

DIAGRAM OF THE VARIOUS FORMS OF EXTERNALLY SECRETING GLANDS

A Simple tubular, e.g. intestinal gland.
B Coiled tubular, e.g. sweat gland.
C Branched tubular, e.g. stomach (fundic) gland.
D Compound branching tubular, e.g. lachrymal gland.
E and F Simple and branched alveolar, e.g. sebaceous glands.
G Compound alveolar, e.g. Meibomian gland of eyelid.
H Branching tubulo-alveolar, e.g. œsophageal gland.
I Compound branching tubulo-alveolar, e.g. salivary gland.

C

Among the protective secretions is mucus, an opaque viscid fluid which keeps many of the internal surfaces moist and slippery. In the large intestine the mucus lubricates the gradually solidifying intestinal contents and assists them to slip easily along the tract without damage to the delicate lining tissue. The linings of the œsophagus, the vagina and certain other passages are similarly moistened. In the stomach and duodenum the same material forms a protective film lining these organs which helps to prevent injury from the acidity of the gastric juice. In the respiratory passages the mucus prevents the tissues from being dried by the air, and by forming a sticky surface helps to retain the dust particles and bacteria which are carried in by the inspired air. The lashing of the cilia then sweeps the mucus and adherent particles away from the lungs.

Mucus secreting cells may be arranged in alveoli, or they may be interspersed between other columnar cells, such as ciliated or absorbing cells. These isolated mucous cells are known as goblet cells, on account of their chalice-like appearance.

Other protective secretions include the oily secretion of the sebaceous glands which keeps the skin pliable and waterproof. The secretion of the tarsal glands have the same effect on the edge of the eyelids, while friction between the anterior surface of the eyeball and the eyelids is prevented by the continuous flow from the lachrymal glands. The acid secreted by the fundic glands of the stomach is antiseptic and destroys many of the bacteria taken in with the food. The teeth owe their extreme hardness to the enamel covering the crowns; this is secreted on to the dentine by the epithelial cells of the enamel organ before the teeth are cut.

Excretory products formed in the body, which would be dangerous if retained, are removed in various ways. In

some instances, such as the excretion of some of the nitrogen compounds by the kidneys, the process is similar to that of secretion. Certain of the cubical cells of the kidney tubules secrete these substances into the tubules for removal from the body in the urine. The sweat glands act, incidentally, as excretory organs by secreting water and dissolved substances on to the surface of the skin for the purpose of losing heat. To some extent the liver cells and the glands of the large intestine are also excretory in function.

Epithelial tissues also form most of the endocrine (internally secreting or ductless) glands, such as the adrenal and thyroid glands, but the cells in these structures are mainly in the form of solid masses or chains and only in a few instances show any free surface formation. There are no ducts, the secretions being passed directly into the blood stream.

5. Absorption

Absorption is a method by which materials are drawn into the cytoplasm through the cell membrane, or into the body through a surface tissue. Absorption, like secretion, is not a purely physical process since it involves active selection of material by the cells. The cells which form absorbing layers are columnar or cubical in shape, and are arranged as a simple tissue. The free edges of such cells are often well defined and have a striated or fibrillated appearance due to modifications of the cytoplasm designed to assist the process of absorption. To provide a larger surface for absorption the tissue may be invaginated, as in the large intestine; or may cover finger-like projections, called villi. These villi are found throughout the small intestine. As the materials are absorbed they pass through the tissue from its free to its basal surface, enter the tissue fluid and are removed by the blood or lymph stream.

6. Ciliary Movement

Ciliated epithelium is responsible for the movement of liquids and solid particles which come into contact with its surface. The ciliated cells are columnar or, occasionally, cubical in shape and are arranged in a stratified, pseudo-stratified or simple tissue, according to the amount of mechanical protection required.

In the respiratory passages the upward lashing of the cilia removes the dust and bacteria which have become adherent to the mucus secreted on to the ciliated lining. This muco-ciliary mechanism is an important factor in preventing clogging of the respiratory membrane.

The Fallopian tubes of the female reproductive system are lined with ciliated simple columnar epithelium which transports the non-motile ova. The funnel-shaped ends of these tubes close to the ovaries are fringed with many finger-like processes also lined with cilia, and the current set up by their inward lashing continually draws in small amounts of serous fluid. When at ovulation an ovum is expelled from either of the ovaries it too is swept almost immediately into the tubule, and is gradually passed down into the uterine cavity.

The cells lining the epididymis and vasa efferentia of the male reproductive tract also have cilia, but these are non-motile and are probably adaptations to assist in the secretion of the seminal fluid.

7. Germinal Function

By means of repeated mitosis the germinal epithelia produce specialized cells from which the sex cells develop. Germinal tissue is found only in the gonads, the testes in the male and the ovaries in the female, where the respective sex cells are formed.

The ovaries in the female body lie in the abdominal

cavity and are covered by a continuation of the peritoneum. The cells of this specialized tissue are cubical, not flattened as in the rest of the peritoneum. By division of these cells groups of cells are forced downwards into the depths of the ovary, where certain of them increase in size becoming the primitive ova. Further changes, including the halving of the number of chromosomes by reduction division, take place before they develop into mature ova. Each maturing ovum is surrounded by a follicle of small cells also of epithelial origin.

The germinal epithelium of the ovary is active only during fœtal life. At birth the full number of primitive ova are present in the ovary. These lie quiescent until puberty when they begin to mature in rotation, a fully developed ovum being discharged from its follicle on to the surface of one or other of the ovaries every twenty-eight days throughout sexual life.

In the testes of the male the germinal epithelium is arranged as the lining of tightly packed coiled tubules. The walls of these tubules appear to be formed of a compound tissue. The many layers represent the various stages of development from the cubical or somewhat flattened cells at the base to the fully developed spermatozoa, complete with tails, projecting into the lumen of the tubule. Isolated columnar cells with supporting and nutritive functions are present in the germinal epithelium, and as the spermatozoa develop they become arranged in groups attached to these cells.

The spermatozoa themselves are motile. Each consists of a head, formed of the nucleus with a film of surrounding cytoplasm, and of a long flagellate tail, comparable with a single cilium. Once the fully mature spermatozoa are passed from the testes they are able to swim by the lashing of their tails in the seminal fluid, a liquid secretion of the genital tract and its accessory glands.

8. Sensory Functions

In the lower parts of most epithelial tissues there are receptor nerve endings. These are the endings of nerve fibres which pass impulses from the epithelium to the central nervous system. For instance, in the lower layers of the epidermis there are "pain" nerve endings. These are fibrillar branchings of the nerve fibres which are sensitive to any stimulus of an intensity sufficient to cause harm to the tissue.

Some surface tissues contain specialized sensory cells. These rarely form the entire surface but are interspersed between undifferentiated epithelial cells acting as supports. The specialized cells are highly responsive to certain stimuli and transmit them to sensory nerve endings lying between the cells. In some places the sensory cells are themselves nervous elements which have grown into the epithelial layer.

The taste buds of the tongue are flask-shaped groups of cells lying in the stratified epithelium of the tongue. The base of the bud rests on the connective tissue corium. The cells themselves are of two types; the sensory or gustatory cells and the deeper supporting cells. The gustatory cells are fusiform in shape, and each ends in a tiny taste hairlet which projects through a minute opening on the surface of the stratified epithelium. Sensory nerve endings between the gustatory cells are stimulated by certain substances in the juices of the food.

Other sensory cells with projecting hair-like processes are found in the ampullæ of the semicircular canals of the ear. They are stimulated by movement of fluid set up by movements of the head. Similar cells in the utricle and saccule of the ear are stimulated by minute concretions of calcium carbonate suspended in mucus, which are affected variously by the pull of gravity in different positions of the head.

In the olfactory membrane, at the roof of the nasal

passages, bipolar nerve cells are supported in the stratified columnar epithelium. These cells are stimulated by volatile aromatic substances in the air as it is breathed in through the nose.

The foregoing are examples of sensory epithelium. A common characteristic of all these sensory surfaces is their protective function, since nerve impulses arising from them give valuable information to the central nervous system of changes in external conditions, or of the position of the body in relation to its environment.

Fig. 6

SIMPLE SQUAMOUS (PAVEMENT) EPITHELIUM OF THE MESENTERY. SURFACE VIEW. × 300.

This is a surface view of simple squamous epithelium. The intercellular material has been impregnated and blackened with silver nitrate, and this demonstrates clearly the small amount of retaining substance in proportion to the cells. The cell shapes are thus shown by this method of preparation, and it can be seen how closely the cells fit together at their edges. The cell contents are not stained, but the position of the nuclei of certain of the cells is indicated by the precipitation of blackened particles on to the surface of the tissue, outlining the slight protrusions caused by the nuclei in the centre of the cells.

Fig. 7

SIMPLE SQUAMOUS (PAVEMENT) EPITHELIUM OF THE PERITONEUM. VERTICAL SECTION. × 500.

This drawing shows a vertical section through the simple squamous epithelium which lines the abdominal cavity. Notice the extreme thinness of the tissue. The cytoplasm of the epithelial cells shows as a thin line resting on the underlying connective tissue; the flattened nuclei, indicative of the shape of the cells, bulging slightly at the free surface. Also shown are several capillary blood vessels and a small lymph vessel. These structures are lined with endothelium which in appearance is similar to the squamous epithelium.

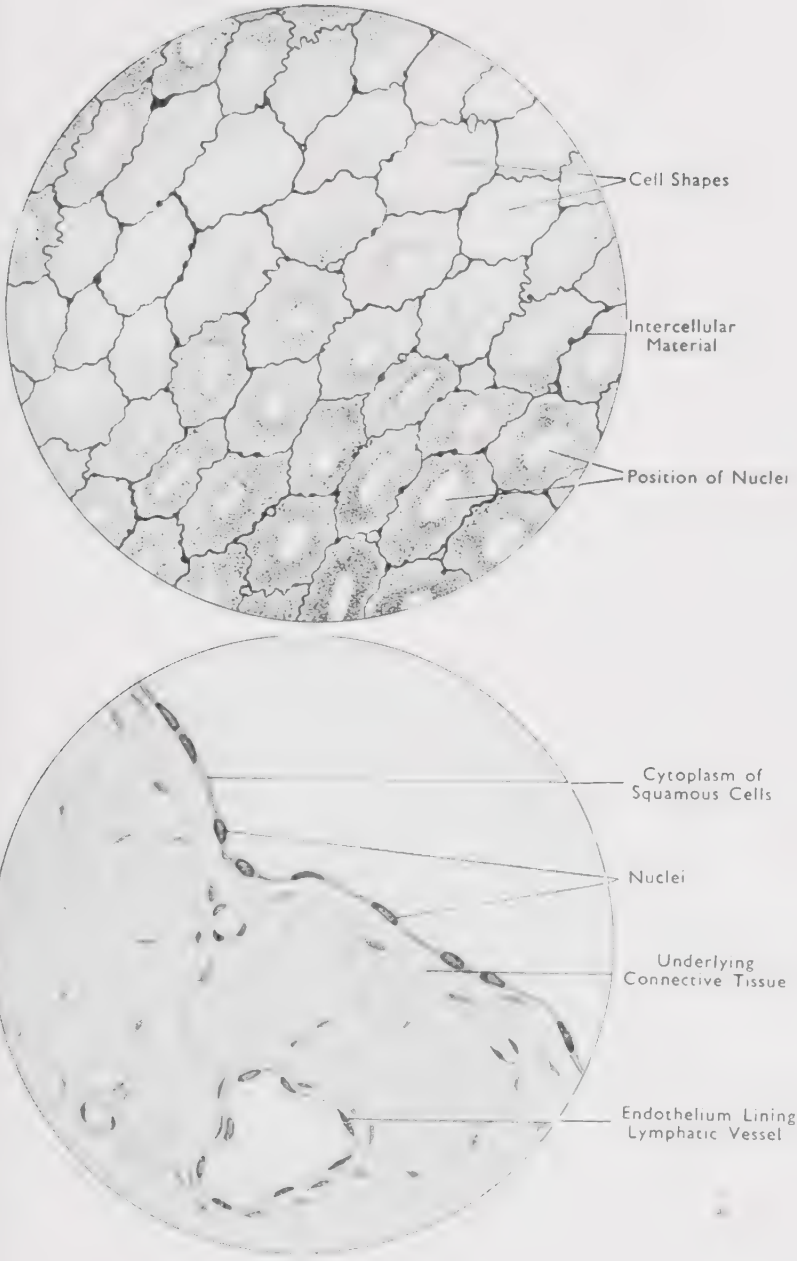

Cell Shapes
Intercellular Material
Position of Nuclei
Cytoplasm of Squamous Cells
Nuclei
Underlying Connective Tissue
Endothelium Lining Lymphatic Vessel

Fig. 8

SIMPLE SQUAMOUS AND CUBICAL EPITHELIUM OF THE KIDNEY TUBULES. × 220.

The simple squamous epithelium forming the outer layer of the Bowman's capsule is shown in vertical section as a very thin strip of tissue with typical flattened nuclei. The inner layer of the capsule is reflected tightly over the central knot of capillaries (glomerulus) and cannot be distinguished. The surrounding convoluted tubules are cut both transversely and lengthwise. Notice the greater thickness and the more rounded nuclei of the cubical epithelium which forms these tubules. The free border of the epithelium, adjacent to the lumen (the central cavity of the tubule), is less clearly marked than is the basal border which is outlined by the basement membrane and by strands of connective tissue. The cells of the convoluted tubules have modified cytoplasm near the free surface. This appears in some preparations as striations in the cytoplasm radiating from the lumen and occupying about one quarter of the cell thickness. It is not shown in this drawing.

Fig. 9

MUCOUS AND SEROUS GLANDS OF THE TONGUE. × 75.

This illustration shows cubical epithelium in glandular form. Both the mucous and serous glands are of the branching tubulo-alveolar type. The ducts can be recognized as distinct from the secreting tissue by their wider and more clearly marked lumens. The cells, and therefore the alveoli of the serous gland, are smaller than those of the mucous gland. The nucleus of each serous cell is large and spherical; this gives the serous gland a "spotted" appearance. The cytoplasm of these cells is dark and granular. The mucous gland, on the other hand, has large clear cells due to the presence of mucin which occupies the greater part of each cell. The nuclei are flattened and displaced to lie at the base of each cell in a small amount of cytoplasm. This, together with the presence of contractile myo-epithelial cells between the mucous cells and the basement membrane, has the effect of outlining the shape of the alveoli. Myo-epithelial cells, though present in the serous glands, are less easily seen.

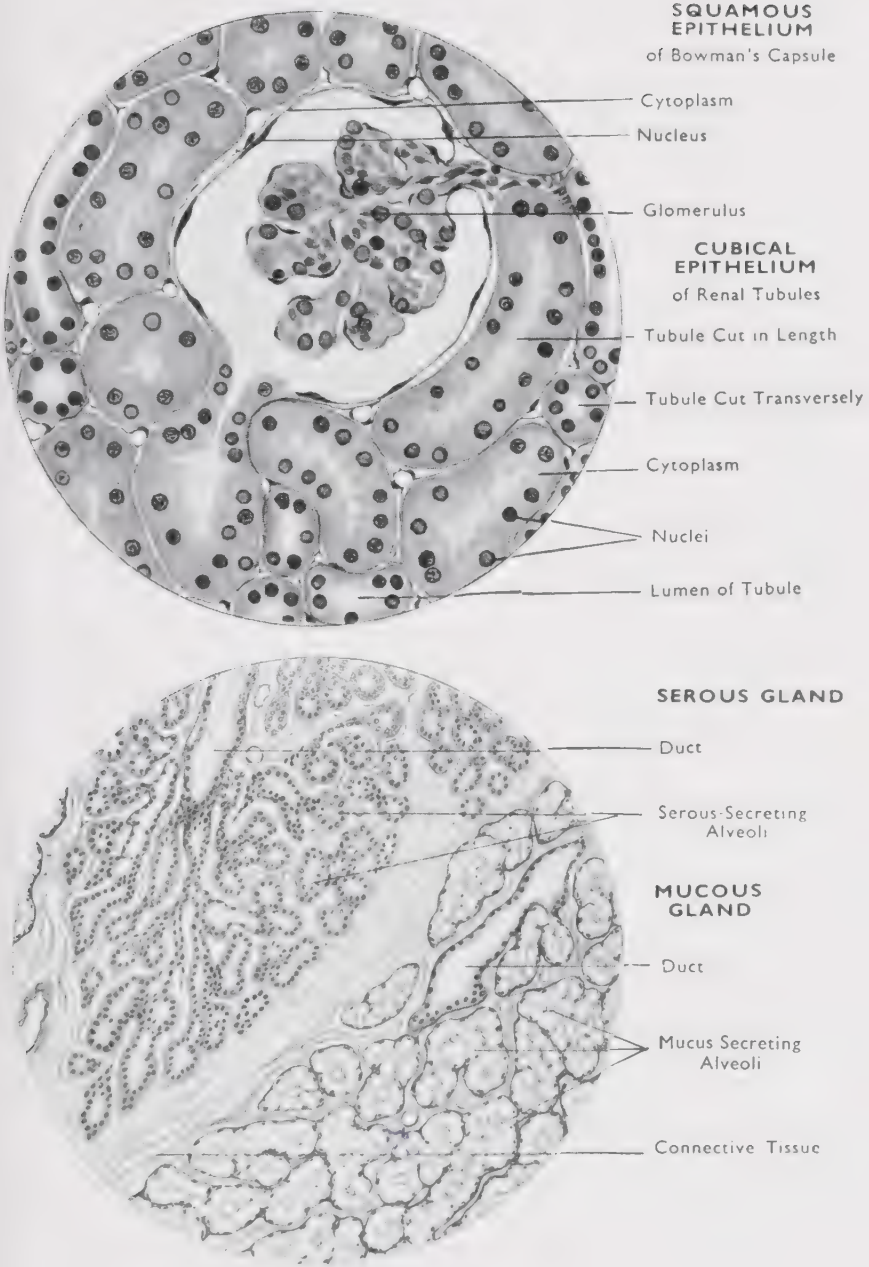

SQUAMOUS EPITHELIUM
of Bowman's Capsule
Cytoplasm
Nucleus
Glomerulus
CUBICAL EPITHELIUM
of Renal Tubules
Tubule Cut in Length
Tubule Cut Transversely
Cytoplasm
Nuclei
Lumen of Tubule
SEROUS GLAND
Duct
Serous-Secreting Alveoli
MUCOUS GLAND
Duct
Mucus Secreting Alveoli
Connective Tissue

Fig. 10

SIMPLE COLUMNAR EPITHELIUM. LINING OF THE GALL BLADDER. × 250.

The columnar epithelium is shown here in vertical section. The cells forming the tissue can be recognized as columnar in shape, even when the cell membranes cannot be distinguished, by the vertically placed rod-shaped nuclei packed closely together. The nuclei tend to lie towards the deep surface of the cells forming a single row indicative of the simple nature of the tissue. In one part the section has passed obliquely through the tissue: here the greater thickness and the many nuclei at various levels gives the appearance of a compound tissue which may be misleading to the inexperienced student. Notice how closely the cells fit together at their free ends, forming a smooth continuous lining.

Fig. 11

SIMPLE COLUMNAR EPITHELIUM WITH GOBLET CELLS. LINING OF THE LARGE INTESTINE. × 250.

The columnar epithelium lining the large intestine is invaginated to form numerous tubular glands. The free edge of the tissue can be followed as it passes down into the tubules. Notice that the nuclei of the cells are placed away from the free edge and nearer to the underlying connective tissue. There are two types of cell making up this tissue. The typical columnar cells can be recognized by the characteristic shape and spacing of the nuclei. Notice that these cells show a definitely marked free border; this is the striated border indicative of cells which are absorptive in function. At intervals between these cells goblet cells can be seen. Each appears like a clear bubble, due to the formation and storage of mucin in the upper part of the cell. In the preparation of the tissue the mucin becomes dissolved and the cell distended by a drop of mucus. The nucleus is displaced by the accumulation of secretion to the base of the cell and appears triangular, lying in a small amount of cytoplasm.

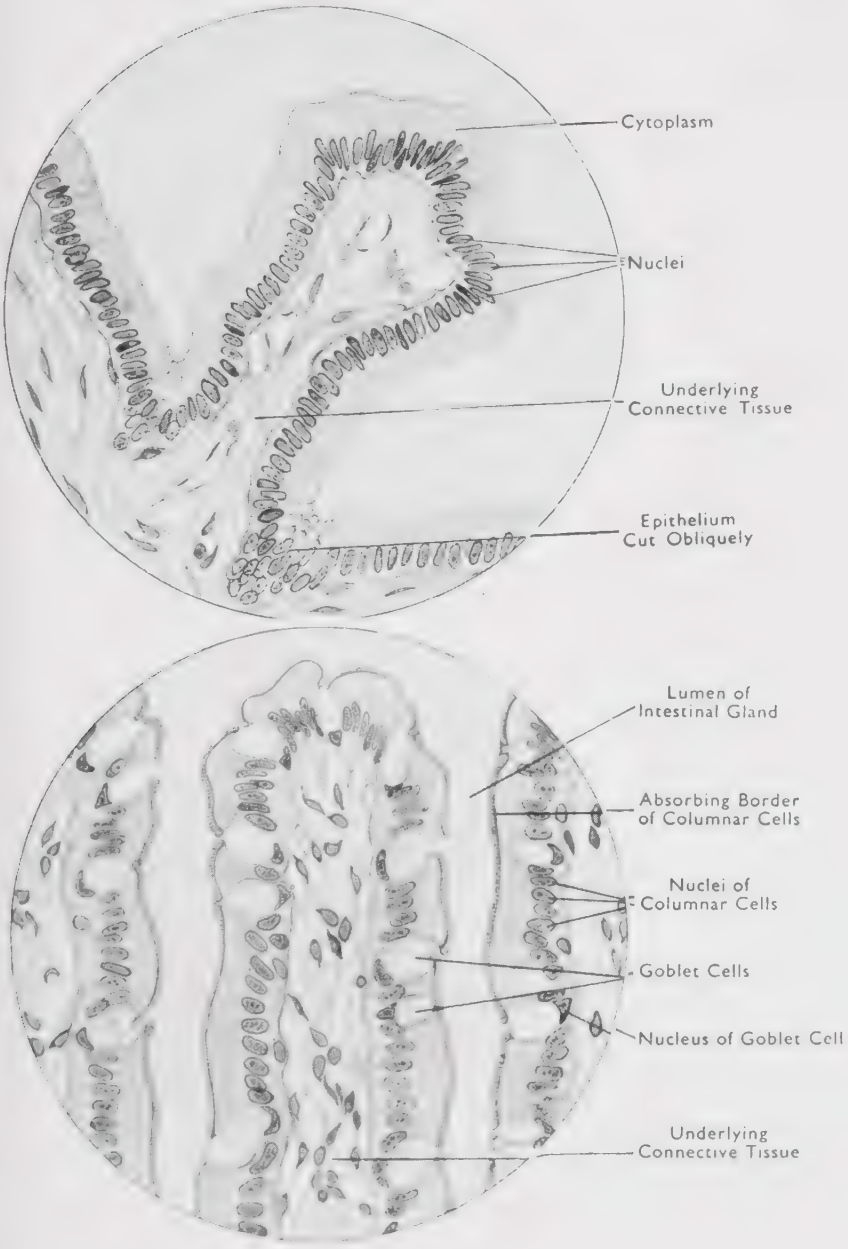

Cytoplasm
Nuclei
Underlying Connective Tissue
Epithelium Cut Obliquely
Lumen of Intestinal Gland
Absorbing Border of Columnar Cells
Nuclei of Columnar Cells
Goblet Cells
Nucleus of Goblet Cell
Underlying Connective Tissue

Fig. 12

CILIATED COLUMNAR EPITHELIUM (PSEUDOSTRATIFIED). LINING OF THE TRACHEA. × 375.

In this tissue the surface cells can be recognized as columnar by the arrangement of their large oval and rod-shaped nuclei: the fringed appearance of the free edge indicates that these cells are ciliated. Between the ciliated cells occasional goblet cells can be seen, their mucous contents giving them a clearer and more globular appearance than the surrounding cells. The presence of smaller cells between the roots of the columnar cells is indicated by the closely packed, more rounded nuclei at the base of the tissue.

Fig. 13

STRATIFIED SQUAMOUS EPITHELIUM. LINING OF THE ŒSOPHAGUS. × 275.

This tissue is seen in vertical section as a comparatively wide band with a smooth free edge and an irregular deep edge due to the upward projections or papillæ of the underlying connective tissue. The whole tissue may be thrown into folds. The thickness of the tissue and the many rows of nuclei are indications of its compound nature. The surface cells, some of which can be seen flaking off, are squamous in shape as is shown by the flattened nuclei. The widely spaced, rounded nuclei of the intermediate layers indicate that the cells are polyhedral. The deep cells can be recognized as columnar by the vertical rod-shaped nuclei. This transition from deep columnar to superficial squamous cells is characteristic of stratified squamous epithelium.

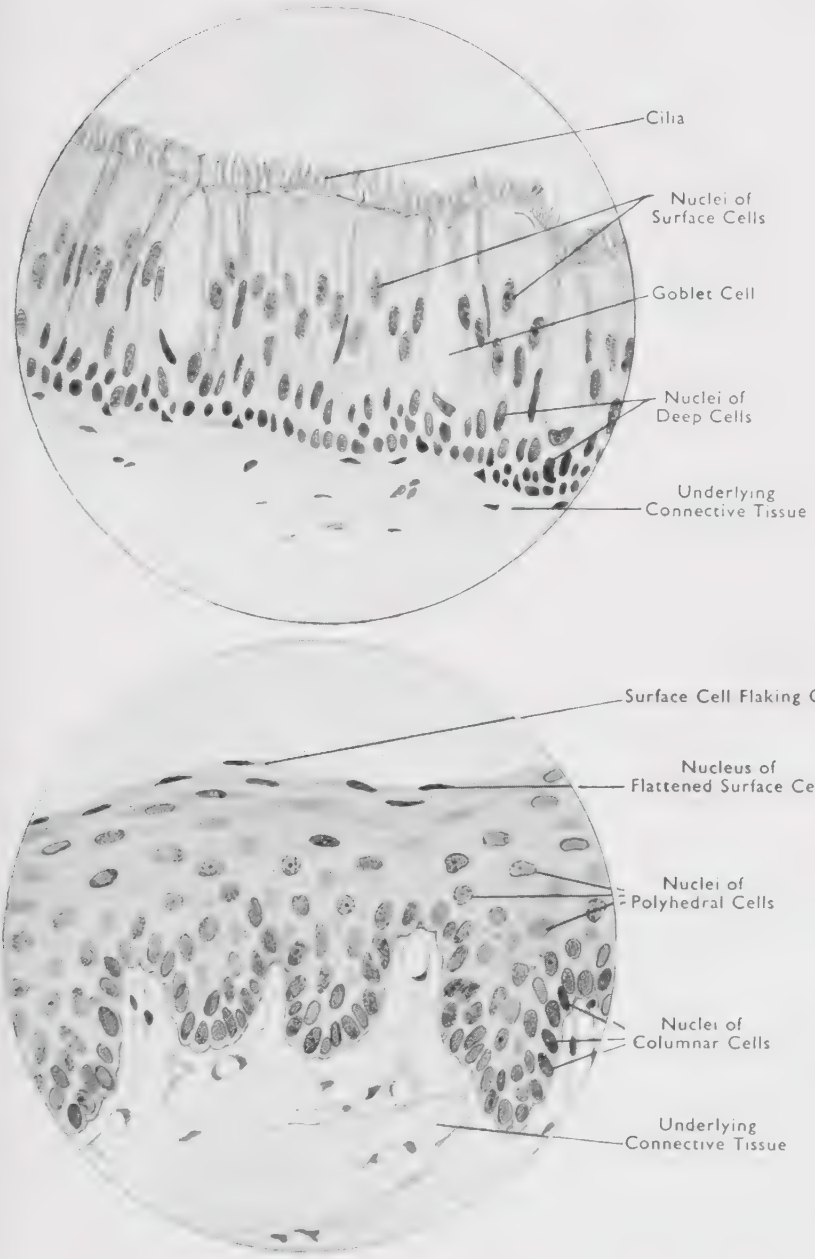

Cilia
Nuclei of Surface Cells
Goblet Cell
Nuclei of Deep Cells
Underlying Connective Tissue
Surface Cell Flaking Off
Nucleus of Flattened Surface Cell
Nuclei of Polyhedral Cells
Nuclei of Columnar Cells
Underlying Connective Tissue

Fig. 14

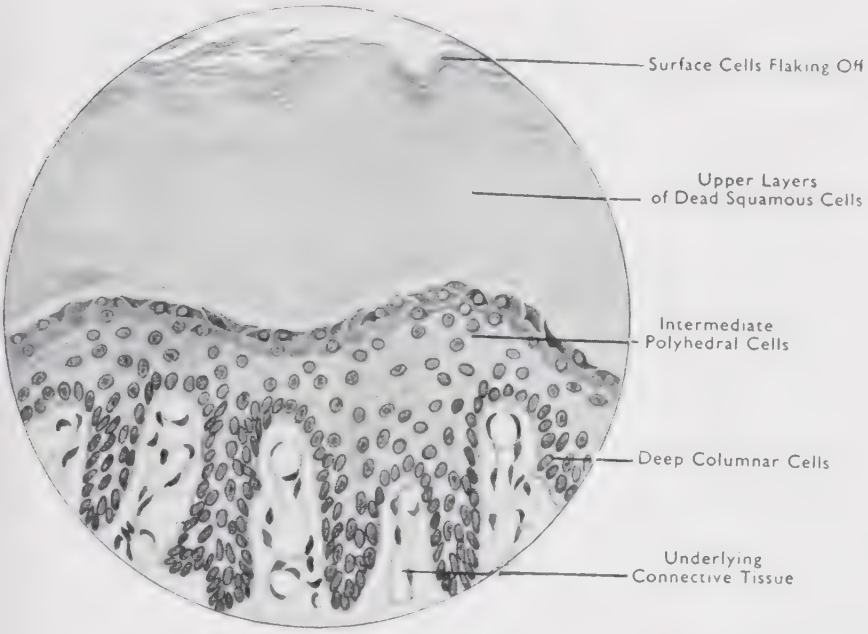
STRATIFIED SQUAMOUS EPITHELIUM. EPIDERMIS OF THE PALM OF THE HAND. × 150.

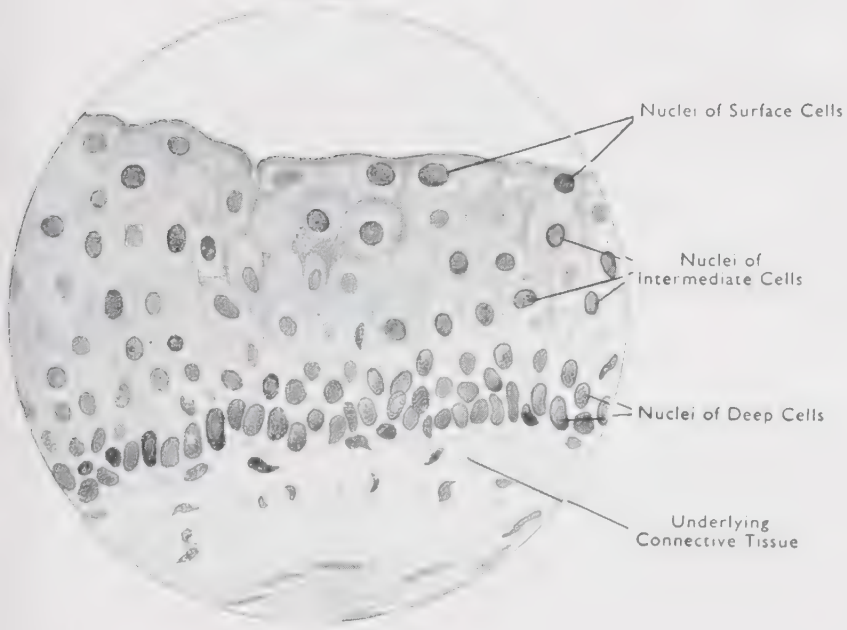
All the characteristics by which stratified squamous epithelium can be recognized are seen here; but the tissue is modified by an increase in thickness and by keratinization. The upper part of the tissue is formed of dead, keratinized cells constituting the stratum corneum. This shows as a thick superficial layer in which the individual cells cannot be seen. Below this is a layer of cells which have lost their power to stain, and which form a clear band, the stratum lucidum, separating the dead from the living layers of the tissue. The layer deep to this is formed of almost flattened cells with darkly staining granules representing the stratum granulosum. Their staining property is due to a substance, the precursor of keratin, which is forming in the cytoplasm. Below this are numerous polyhedral cells with rounded nuclei constituting the rete mucosum. These cells are formed by the continual division of the columnar cells of the deepest layer, the stratum germinativum.

Fig. 15

TRANSITIONAL EPITHELIUM. LINING OF THE URINARY BLADDER. × 325.

In vertical section, transitional epithelium may be recognized as a compound tissue by its depth and the many rows of nuclei indicating the layers of cells. Unlike those of stratified squamous epithelium the nuclei show practically no change of shape from the deep to the surface layers. The cells of the deepest layers are small and columnar in shape as is indicated by the shape and close arrangement of their nuclei. The cells of the other layers have widely spaced and more spherical nuclei, including the surface cells, which, unlike those of stratified squamous epithelium, are large, protoplasmic and living. The downward projections from the deep surface of these cells can sometimes be seen, and their rounded free surfaces are often clearly marked due to the presence of a thin non-protoplasmic cuticle.


Surface Cells Flaking Off
Upper Layers
of Dead Squamous Cells
Intermediate
Polyhedral Cells
Deep Columnar Cells
Underlying
Connective Tissue


Nuclei of Surface Cells
Nuclei of
Intermediate Cells
Nuclei of Deep Cells
Underlying
Connective Tissue

D

CHAPTER IV

THE CONNECTIVE AND SUPPORTING TISSUES

General account of the connective and supporting tissues and of their common characteristics, together with a detailed account of the connective tissues proper; these constituting a subdivision of the tissue group.

THE connective and supporting tissues are an extensive group of tissues whose rôle in the body's architecture is largely mechanical. The tissues fall into three main groups: the connective tissues proper, the cartilages, and bone. These ensure the body's structural integrity by forming a firm internal supporting system, which allows movement and provides leverage for the action of muscles; they support or ensheath specialized structures, connect together more active tissues into functional units, and altogether render the body a compact entity. The several tissues are suited to their functions and positions by their individual physical properties. Blood also is a member of the connective tissue group, having the same embryonic origin and many of the common characteristics; but its unique distribution and functions qualify it for separate consideration.

GENERAL CHARACTERISTICS

In contradistinction to the epithelia, these tissues are composed largely of intercellular material whose consistency is important in determining the physical properties of the individual tissues. The intercellular material consists of a ground substance or matrix, which in most cases contains a variable proportion of fibrous elements. The

matrix of the connective tissues proper is a soft jelly; in cartilage it is firm but resilient; while in bone it is dense and rigid, due to the incorporation of inorganic salts.

The fibres are of three types. The yellow or elastic fibres develop from granules of a protein, elastin, deposited

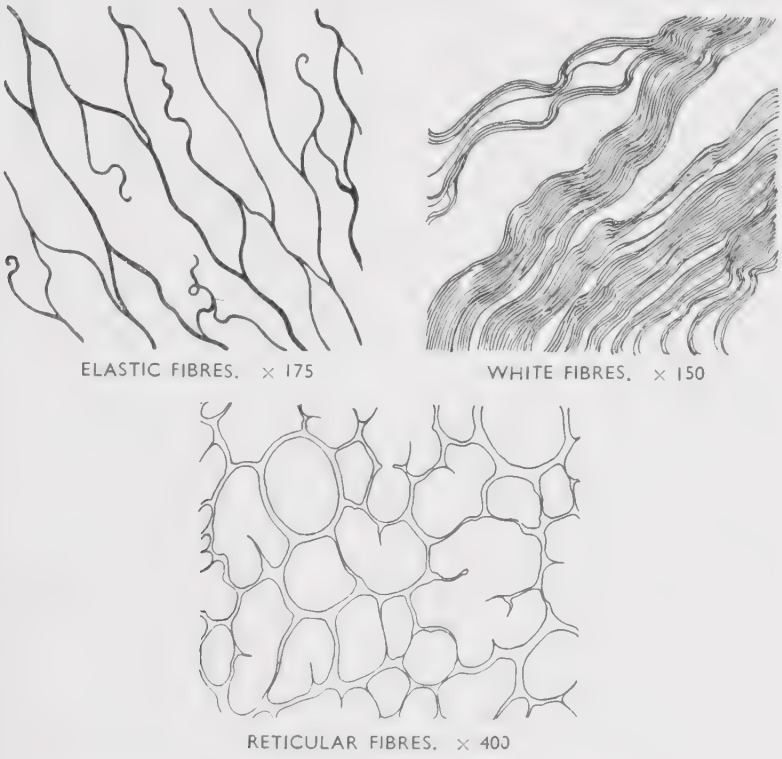


Fig. 16
DIAGRAM OF THE VARIOUS CONNECTIVE TISSUE FIBRES

in the matrix, probably by the connective tissue cells. These fibres are extensible, highly elastic, and comparatively thick and strong. They branch and anastomose freely, forming a wide network in tissues subject to extension in all directions; or having a more parallel arrangement where the tension is predominantly from one quarter.

The collagenous or white fibres are manufactured by certain connective tissue cells. They are extremely fine unbranching threads which lie in bundles of varying thickness. When present in large numbers they give the tissue an opaque white appearance, although they are individually colourless. They are both inextensible and inelastic, and though very pliable they are extremely strong in resistance to tearing forces. These fibres always lie in the line of greatest stress in a tissue, and it is probable that their formation is actually stimulated by continual tension in any particular direction. When the tension is removed the fibres assume a wavy or folded position owing to their inelasticity.

A third, probably more primitive, form of fibre is found in some connective tissues. These are fine branching fibres, which form a reticulum throughout the tissue, hence their name of reticular fibres. By their arrangement they allow considerable "give" in a tissue, but the fibres themselves are inextensible and inelastic. In places they are continuous with the unbranching white fibres.

The connective tissue cells generally lie in cell spaces, or lacunæ, in the matrix, and are comparatively widely separated, though in many cases they retain contact with each other by anastomosing branches. The various cells can be divided into two main groups: the fibrocyte group, or true connective tissue cells, and the histiocytes, which are related to the white cells of the blood. Typical fibrocytes are flattened irregular cells with large ovoid nuclei and clear surrounding cytoplasm. These cells are attributed with the formation of the matrix and its fibres, in particular the white fibres; in this capacity they are sometimes termed fibroblasts. Similar cells, known as chondroblasts, are responsible for the laying down of cartilage matrix; in mature cartilage they are termed chrondrocytes. Bone-forming cells are called osteoblasts, and the cells in the bone tissue itself are known as osteocytes. All these cells

are active in the repair of injury and the formation of scar tissue. Some connective tissue cells have the capacity for storing fat and are the principal cells of adipose tissue. In the less specialized connective tissues the cells retain a capacity for modification into the other more specialized forms as the need arises. Certain specialized cells, such as the fat cells, can also revert to the undifferentiated state.

The cells found in the connective tissues which are related to the blood cells include the histiocytes (or tissue macrophages). These cells lead an exclusively extravascular existence, although similar in many ways to typical white blood cells. They are phagocytic and act as scavengers in the tissues. Under normal conditions some are stationary, but in inflammation many develop the power of amœboid movement and travel to the affected part. A type of cell found in comparatively small numbers is the "mast" cell. These cells have granular cytoplasm and are thought to manufacture heparin, the anticoagulant of the blood: (page 105). Lymphocytes (a type of white blood corpuscle) may also be found, often in considerable numbers. Other white blood cells of all types may be present as wandering cells, having penetrated through the capillary walls into the tissues.

As the connective and supporting tissues are concerned with mechanics of structure rather than with physiological activities, they contain few or no effector (activating) nerve endings, but they support nerve fibres passing to other tissues. Many receptor (sensory) nerve endings are encapsulated in connective tissue.

The connective tissues proper vary in their vascularity according to their function. Those tissues which form strengthening structures, such as ligaments, have a limited blood supply; but where they form ensheathing or supporting layers for active tissues they are highly vascular. The bone tissues also are vascular, but cartilage generally contains no blood vessels; the cartilage cells depend for

their nutrition on diffusion through the matrix from the blood vessels in the surrounding connective tissue.

The connective and supporting tissues often merge into one another without any clear cut boundary and the transitional zone is sometimes extensive. An accurate and complete classification is difficult to make owing to the numerous intermediate types.

THE CONNECTIVE TISSUES PROPER

This group of tissues includes areolar tissue, adipose tissue, white fibrous tissue, yellow elastic tissue and reticular tissue. Lymphoid tissue and bone marrow are specialized blood-forming tissues developed in reticular tissue.

Areolar Tissue

Areolar tissue is the most widely distributed and typical of the connective tissues. It is exceedingly fine and softly pliable, pearly white in colour and crossed by numerous very fine white threads. In spite of its delicate nature it offers considerable resistance to tearing, and is somewhat elastic.

The pliancy of this tissue is due to its transparent semi-fluid matrix. In this matrix are fine yellow elastic fibres branching freely in all directions and adding to the tissue's elasticity. There are also white fibres arranged in typical wavy bundles, which dividing and reuniting form an interlacing network that contributes greatly to the strength of the tissue. It is these fibrous bundles that appear as white threads to the naked eye.

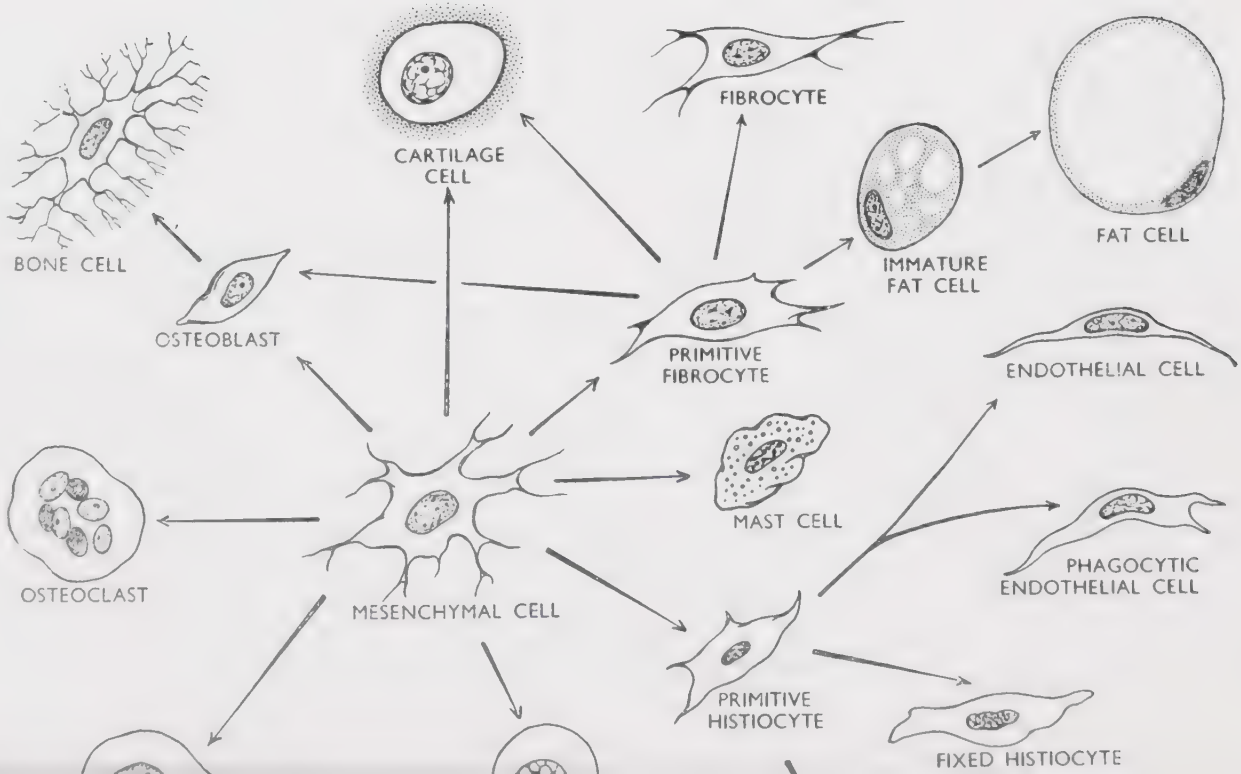
Areolar tissue contains a variety of cells. The most numerous are the fibrocytes and the histiocytes, but wandering blood cells, lymphocytes and mast cells are also present. In some positions the fibrocytes may contain pigment granules.

Areolar tissue is found in almost every part of the body. It forms the basic tissue which supports or surrounds the more specialized structures. It is found between organs and muscles, supporting blood vessels and nerves, and forming delicate and vascular membranes around such organs as the brain and spinal cord. It penetrates also into the depths of organs between the layers or masses of tissue, separating and cushioning them. While it allows movement between adjacent structures it inhibits distortion.

Areolar tissue is adapted to the mechanical requirements of the different parts of the body by variations in the total density and relative proportion of its constituent fibres. As a dense, fibrous feltwork it forms the dermis of the skin, supporting the stratified epithelium and its accessory structures, and giving the skin the necessary toughness, resilience and depth of tissue to withstand injury and to protect underlying organs.

In positions where mobility is essential, areolar tissue assumes a very fine, loosely woven form. Such is the tissue which, as superficial fascia, connects the deep layers of the skin to underlying structures. This allows the skin to be moved moderately freely, while the movements of the underlying muscles and bones are virtually unrestricted by their attachment to it. Very loose areolar tissue is found between the individual fibres and fibre bundles of muscles, and surrounding tendons and ligaments. In these positions also its extreme softness and pliancy is important in allowing easy movement. In certain places continual movement causes an actual separation of the tissue: the cleft or cavity so formed becomes lined with histiocytes in the form of endothelium: (page 23).

Where necessary, additional resilience and elasticity are given to the areolar tissue by the presence of a greater number of elastic fibres and, where the tissue is called upon to withstand more continual strain, the numbers of


BONE CELL
CARTILAGE CELL
FIBROCYTE
IMMATURE FAT CELL
FAT CELL
OSTEOBLAST
PRIMITIVE FIBROCYTE
ENDOTHELIAL CELL
MAST CELL
OSTEOCLAST
MESENCHYMAL CELL
PHAGOCYTIC ENDOTHELIAL CELL
PRIMITIVE HISTIOCYTE
FIXED HISTIOCYTE

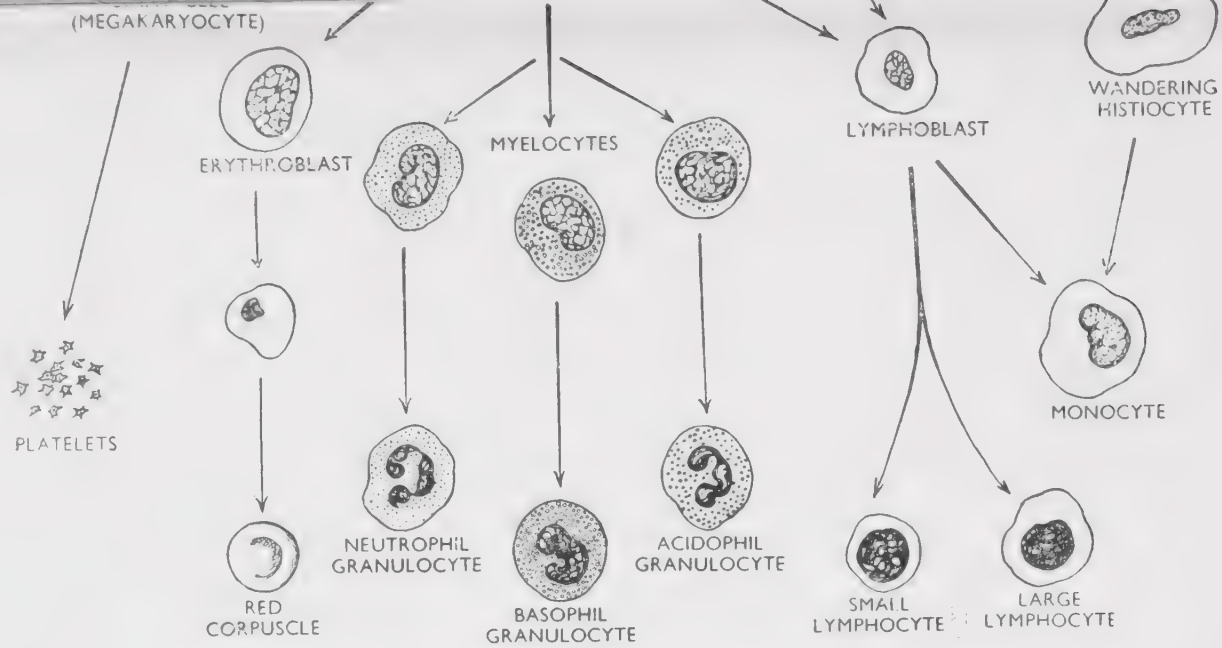


Fig. 17

DIAGRAM OF THE VARIOUS CONNECTIVE TISSUE CELLS, SHOWING THEIR RELATIONSHIP AND THEIR COMMON ORIGIN FROM THE EMBRYONIC MESENCHYME

(Not all stages of development are depicted)

the white fibres are increased. In certain positions areolar tissue shows marked potentialities for development into the more specialized forms of connective tissue—adipose tissue, white fibrous tissue and yellow elastic tissue.

Adipose Tissue

Adipose tissue is specialized areolar tissue in which there is a preponderance of fat-containing cells. When the intake of energy-giving foods into the body is in excess of immediate requirements, storage in the form of fat takes place. Undifferentiated connective tissue cells absorb minute droplets of fat which accumulate in their cytoplasm causing them to swell. The lobules of adipose tissue are composed of masses of tightly packed fat cells, separated only by small quantities of matrix and a few undifferentiated cells. The fibres and blood vessels are displaced, and act as a supporting reticulum around the lobules. When expenditure of energy in the body exceeds the intake of energy-giving foods, these fat stores can be drawn upon to supply the deficit. As the fat is withdrawn from the cells they revert to their undifferentiated form.

Adipose tissue acts also as a firm but resilient packing material around and between organs. It is found between bundles of muscle fibres, in nerves, and supporting blood vessels. In all these positions it offers mechanical protection to the structures it supports.

Subcutaneous adipose tissue is present in the superficial fascia. In this position it acts as a good shock absorber and provides protection for underlying structures. It gives the body a more continuous outline by filling in the concavities and rounding off the bony points. Because fat is a poor conductor of heat, this layer insulates the body against excessive heat loss or heat gain through the skin. As the fat in the cells is semifluid at body temperature, the

tissue has a fair degree of flexibility. Some subcutaneous fat is always present, and does not normally interfere with the mobility of the body, but excess fat storage causes distension of the skin and limitation of movement.

White Fibrous Tissue

White fibrous tissue is formed almost exclusively of tightly packed bundles of unbranching collagenous fibres. The fibre bundles lie parallel to the lines of greatest stress in the tissue. Elastic fibres are few or absent, and there is a minimum of semifluid matrix. The fibrocytes lie in rows, compressed between the bundles, so that their cytoplasm is flattened into wing-like projections. This tissue is extremely strong, inextensible and inelastic. It is, however, moderately pliable, so that unless under tension it does not limit movement, but is thrown into folds.

White fibrous tissue is found where a combination of pliability and tensile strength is required. It forms the strong ligamentous bands that unite articulating bones. All joints are surrounded by a capsule of white fibrous tissue, which is further strengthened by distinct bands. These ligaments generally blend with the external surface of the capsule, but some pass inside the joint cavity. Ligaments are important structures in limiting the movement of joints. Movements in normal ranges are unrestricted, but as soon as the ligaments on any aspect of a joint become taut, further movement is prevented. In certain of the freely movable joints the length of the capsule and the ligaments is such that they play little or no part in maintaining the articular surfaces in contact. This, as will be seen later, is dependent on muscle tone: (page 129).

Every bone is invested by a vascular fibrous membrane, the periosteum, which is firmly attached to the external surface. Blood vessels pass from the periosteum into

canals penetrating the bone tissue. The deep layer of the periosteum is slightly elastic and contains numerous bone-forming cells (osteoblasts), which are important in the growth and repair of the bone. The outer layer is densely fibrous; it forms a strong protective covering for the bone and gives attachment to muscles. The white fibres from the connective tissue in the muscle may blend so closely with the periosteum that the muscle appears to be adherent to the bone itself. Often, however, the fibres pass into fibrous tissue cords (tendons) or flattened sheets (aponeuroses) before becoming attached. In all cases the fibrous tissue provides an unrelenting means of attachment which transmits the pull of the muscle directly to the bone without loss of efficiency. Surfaces for the attachment of muscle fibres are afforded also by fibrous intersections and bands in the depths of some muscles, and by the deep fascia. Deep fascia is the term given to the sheets of fibrous tissue which ensheath groups of muscles and penetrate between them as intermuscular septa, or stretch between parallel bones as interosseus membranes.

Tendons are sometimes retained in position by sheaths or bands of white fibrous tissue. In some cases the action of a muscle is determined by its tendon passing through a loop of fibrous tissue which alters the angle of its pull.

White fibrous tissue forms strong investing membranes, such as the dura mater surrounding the brain and spinal cord, and the fibrous capsules of the liver, the kidneys and the lymphatic glands. It ensheaths nerves and forms the outer coat of blood vessels, being thicker in the veins than in the arteries. It forms the external layer of the pericardial sac which encloses the heart. It is also one of the main constituents of the valves of the heart, and of the valves in the veins, giving pliancy for movement with strength to resist the back pressure of the blood.

Yellow Elastic Tissue

Yellow elastic tissue contains a predominance of elastic fibres. In some places the fibres are so blended as to form an almost continuous elastic lamina. Supporting the fibres there is a small amount of matrix which also contains some connective tissue cells and a few white fibres. This tissue is extensible, highly elastic and flexible. In concentrated form it has considerable strength.

Yellow elastic tissue enters into structures which require both mobility and an ability to recoil. It is found in organs subject to repeated alteration in size or shape, such as the trachea, bronchi and bronchioles, the lungs and visceral pleura, the visceral layer of the pericardium and the walls of the blood vessels, particularly the arteries. As dense cords or bands it forms certain atypical ligaments, notably the ligamentum subflava, the spring ligament of the foot (plantar calcaneo-navicular ligament), and the ligamentum nuchæ. These ligaments allow movement in the joints over which they pass, but unlike the typical white fibrous ligaments they assist in restoring and in maintaining the original positions.

Reticular or Retiform Tissue

Reticular tissue is a primitive type of connective tissue. It differs from all the tissues previously described in having a framework of fine branching fibres. The main cells of the tissue are histiocytes, here often termed reticular cells. These are flat branching cells which enwrap the fibres and have phagocytic properties. The interstices of the reticulum are filled with tissue fluid in place of a true matrix, and contain some lymphocytes and a few wandering blood cells.

Reticular tissue is found in the stomach and intestines supporting the glands of the mucous membrane. It also forms the framework of certain organs such as the liver, the anterior pituitary gland and all the lymph organs.

The reticular cells form a somewhat incomplete endothelial lining to the blood sinuses of the spleen, the red bone marrow, the adrenal glands, the anterior segment of the pituitary gland and the liver: (in this last position they are referred to as the stellate cells of Kuppfer). These cells are continuous with the endothelial cells of the blood vessels, but differ from them in possessing phagocytic and amœboid properties. Reticular tissue forms the basis of lymphoid tissue and of bone marrow.

Lymphoid Tissue

When vast numbers of lymphocytes are lodged in the meshes of reticular tissue it is known as lymphoid or adenoid tissue. Lymphoid tissue is present in the lymph glands, the spleen, the tonsils and adenoids, the vermiform appendix and the thymus gland. To a lesser extent it is found in the stomach and intestines, in the urinary bladder and in the lungs.

In most places the tissue is arranged in concentrated spherical or ovoid masses or nodules, each representing a germinal centre for the formation of lymphocytes. The lymph nodules are often massed together separated only by narrow channels of reticular tissue, as in the lymph glands and the tonsils. In the spleen they are found in close association with the arterioles, and are here termed Malpighian corpuscles. Solitary lymphatic nodules occur in various parts of the body, including the alimentary canal and the lungs.

In the centre of each nodule are numerous lymphoblasts derived from undifferentiated reticular cells. The lymphoblasts divide repeatedly by mitosis to form lymphocytes. The newly formed lymphocytes are gradually pushed to the periphery of the mass, where they float out into the fluid of the reticular tissue and pass by the lymph stream to the blood. The monocytes of the blood are also possibly formed in these centres.

The lymph organs are capable of increasing the speed of production of lymphocytes in response to infection, and they are important in preventing the spread of infection along the lymph channels to the blood stream.

Red and Yellow Bone Marrow

Red marrow is a highly vascularized blood-forming tissue, found in the interstices of the cancellous bone tissue. The red marrow is supplied by the nutrient artery which passes through the outer compact bone to the central cancellous tissue, where it branches extensively to form an intercommunicating network of expanded capillaries or sinusoids, lined incompletely by phagocytic reticular cells. These sinusoids are the site of the formation of the red blood corpuscles. At any one time a certain number of sinusoids are filled with red cells in various stages of development.

In the extravascular spaces the reticular tissue supports a variety of cells. These include undifferentiated blood-forming cells (hæmocytoblasts), which give rise to the marrow cells or myelocytes. These in turn form the granular white cells of the blood: (page 101). The myelocytes show differential staining reactions like the granular cells which develop from them, but their cytoplasm is less granular and they have rounded or bean-shaped nuclei. Small numbers of lymphocytes and monocytes may possibly be formed in the red marrow as well. The mature white cells pass through the sinusoid walls by amœboid movement to enter the blood stream. A few fat cells and some giant cells (megakaryocytes) are also present. The giant cells are large and irregularly shaped with highly lobulated nuclei. They are thought to be responsible for the formation of the platelets of the blood by the protrusion of processes of their cytoplasm through the sinusoid walls. These processes break away and pass as platelets into the blood stream: (page 102).

In young children the cancellous tissue of all bones contains red marrow, but later this is partially replaced by yellow marrow. Yellow marrow consists principally of fat cells supported by a minimum amount of reticular tissue and comparatively few blood vessels. Between middle childhood and puberty yellow marrow begins to accumulate in the shafts of the long bones of the limbs. It first appears in each bone as a central mass, but gradually extends towards the extremities of the bone. In adults red marrow persists in the cancellous tissue of the ribs, the vertebræ, the sternum, the skull and the hip bones, and in small amounts in the extremities of the long bones. In emergencies yellow marrow can become highly vascularized and resume blood-forming functions.

THE RETICULO-ENDOTHELIAL OR MACROPHAGE SYSTEM

This is not a system in the anatomical sense of the word, but a widespread distribution of phagocytic cells of related types. Their scavenging function keeps the tissues clear of deleterious material including cell fragments, dead cells and particles of foreign matter.

The cells of this system include the histiocytes in the various connective tissues; the reticulo-endothelial cells lining the blood sinuses of the liver, the spleen, the red marrow, the anterior pituitary and the adrenal glands; the endothelial cells lining the joint cavities, and the monocytes of the blood; (page 102).

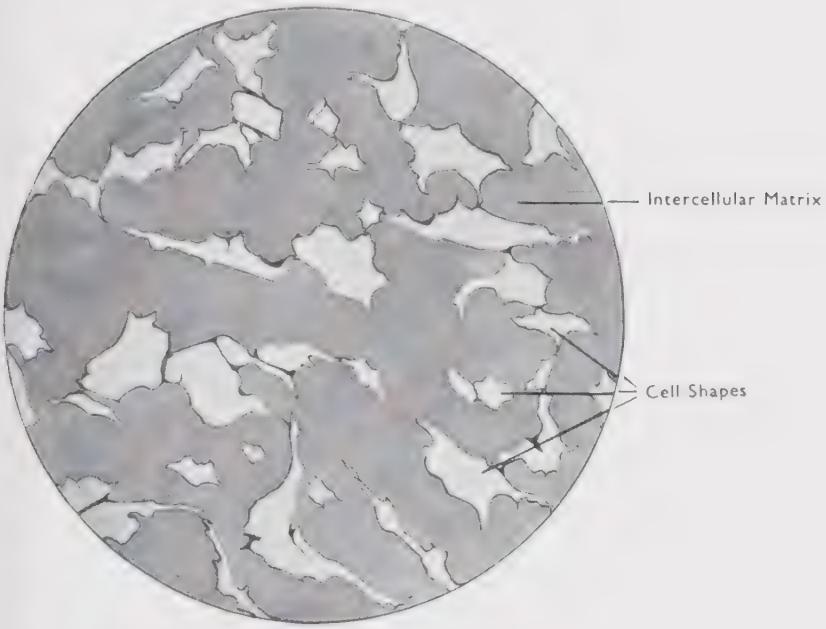


Fig. 18

AREOLAR TISSUE. × **200.**

This is a stretch preparation of areolar tissue in which the intercellular matrix is heavily impregnated with silver nitrate. The light patches indicate the positions and shapes of the connective tissue corpuscles. This method of preparation demonstrates the large amount of intercellular material present in the connective tissues: it shows also the scattered arrangement and the irregular shapes of the cells. Compare this drawing with that of simple squamous epithelium similarly treated, on page 40.

Fig. 19

AREOLAR TISSUE. × **275.**

This also is a stretch preparation of areolar tissue, but it differs from the previous one in that all parts of the tissue are stained. The elastic fibres can be seen running singly, branching and rejoining. In some places the recoiled ends of broken elastic fibres show. The white fibres cannot be seen individually but the bundles appear as shadowy bands. The matrix between the fibres is faintly stained. The nuclei of the various corpuscles have stained deeply and the two principal types of cell may be distinguished by them, the nuclei of the fibrocytes being larger and less darkly stained than those of the histiocytes. The shapes of the cells cannot be seen since the cytoplasm has the same staining reaction and refractive index as the surrounding matrix.

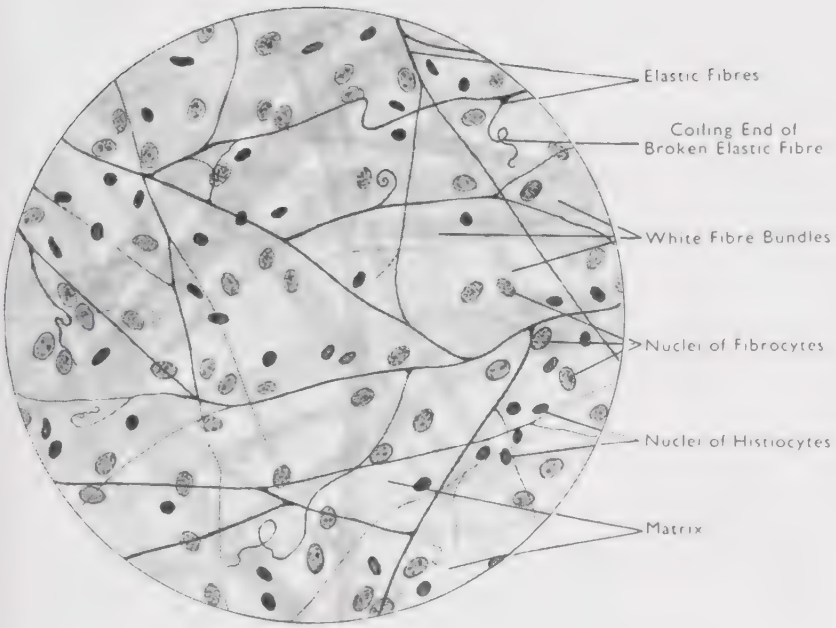

Elastic Fibres
Coiling End of Broken Elastic Fibre
White Fibre Bundles
Nuclei of Fibrocytes
Nuclei of Histiocytes
Matrix

Fig. 20

ADIPOSE TISSUE. × 150.

This tissue is formed largely of masses of cells which have become distended with fat. The intervening connective tissue fibres, matrix and blood vessels are displaced into strands which run between and support the lobules of fat cells. In the preparation of the tissue the fat droplets have been dissolved so that the central part of each cell is left as a clear empty space. The cytoplasm has been displaced to form a thin surrounding membrane or envelope which enclosed the fat, and which contains the flattened nucleus. Where the adipose tissue is well developed the cells are in close contact and their cytoplasmic envelopes are flattened by mutual compression causing a "wire-netting" appearance. In the less developed parts of the tissue the cells are more spherical or ovoid and can be seen individually. The nuclei present between the fat cells belong to undifferentiated fibrocytes and histiocytes.

Fig. 21

WHITE FIBROUS TISSUE OF A TENDON. LONGITUDINAL SECTION. × 500.

This preparation is a section of tendon cut in line with the tendon fibres. It shows the bundles of white fibres as wavy bands running parallel to each other: the individual fibres cannot be seen as they are so fine. Lying in rows between the fibre bundles are the fibrocytes. They are so compressed by the fibres that only their nuclei show as thin dark lines. A certain amount of looser, more cellular areolar tissue is present between the groups of fibre bundles.

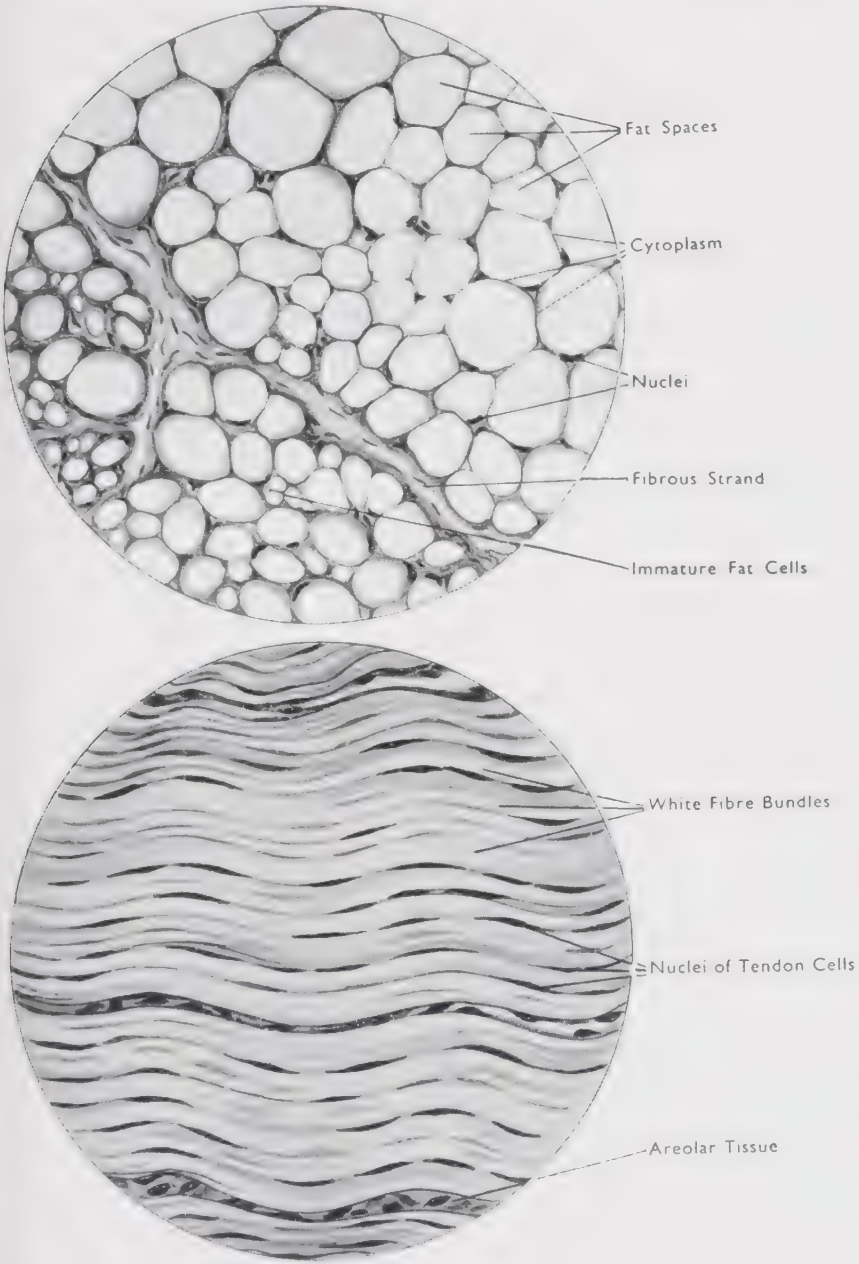

Fat Spaces
Cytoplasm
Nuclei
Fibrous Strand
Immature Fat Cells
White Fibre Bundles
Nuclei of Tendon Cells
Areolar Tissue

Fig. 22

WHITE FIBROUS TISSUE OF A TENDON. TRANSVERSE SECTION. × 600.

The section has been made at right angles to the length of the tendon. The bulk of the tissue is formed of white fibres massed into bundles which are here cut transversely. Between the smaller fibre bundles the fibrocytes can be seen, modified by compression of their cytoplasm into flattened wing-like processes which extend between the fibres causing the X, Y and T shapes characteristic of tendon cells. The whole of the tendon is ensheathed by areolar tissue which also penetrates into the tendon, separating the larger groups of fibre bundles and supporting the blood vessels.

Fig. 23

YELLOW ELASTIC TISSUE. TRANSVERSE SECTION OF AN ELASTIC ARTERY. × 80.

In this preparation the elastic fibres only have been stained so that they stand out distinctly from the other tissues in which they lie. They show as dark curling threads running in a circular manner in the artery wall. The amount of recoil in the fibres is greater here than when the artery is distended with blood during life. The majority of the fibres run singly though there is a certain amount of branching which cannot easily be seen. Surrounding the lumen the fibres run parallel to the length of the artery and are so blended as to form an almost continuous sheet of elastic substance, the internal elastic lamina. This forms the supporting layer for the artery lining.

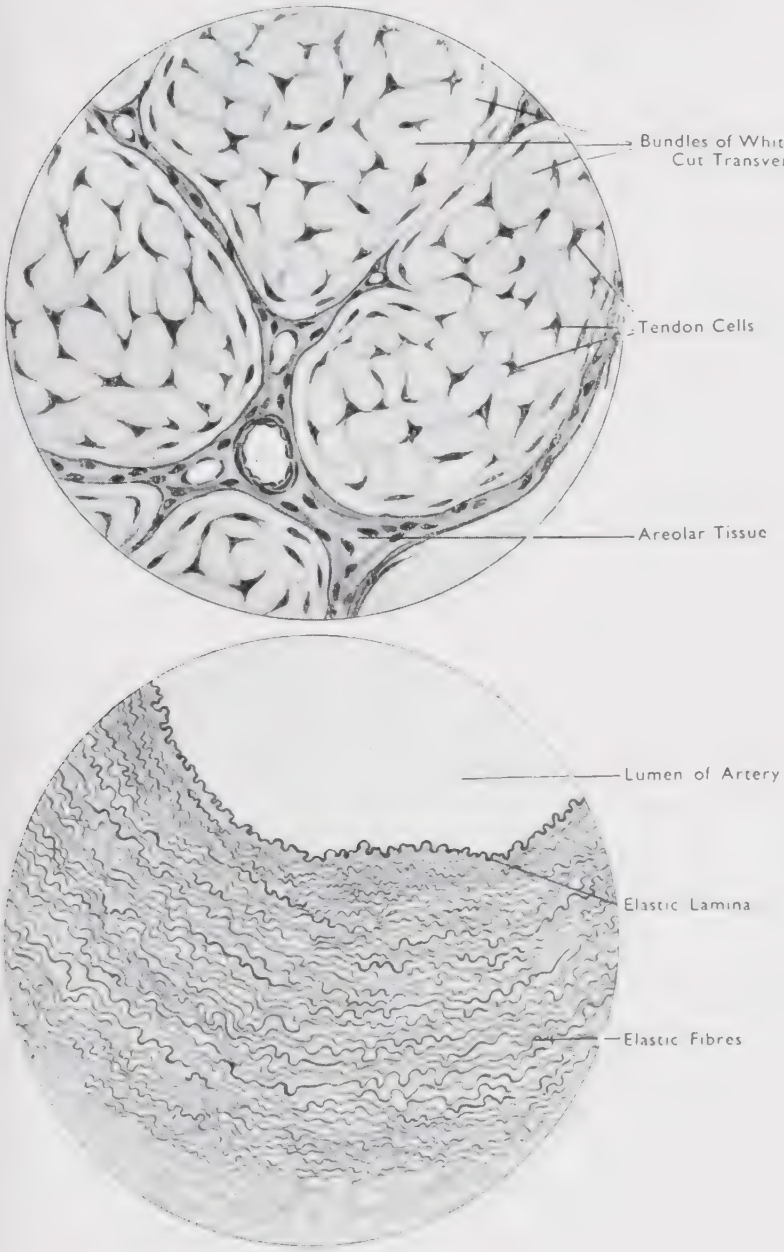

Bundles of White Fibres
Cut Transversely
Tendon Cells
Areolar Tissue
Lumen of Artery
Elastic Lamina
Elastic Fibres

Fig. 24

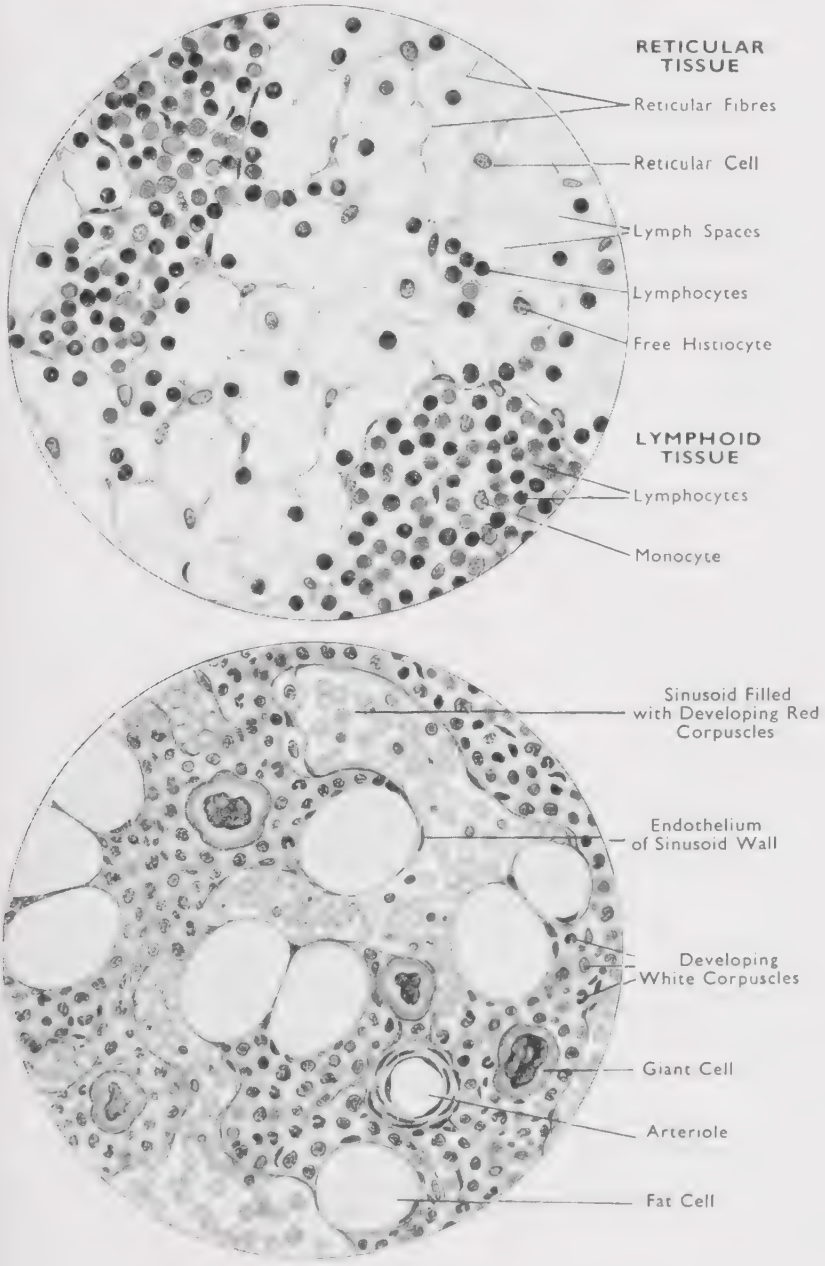
RETICULAR AND LYMPHOID TISSUE OF A LYMPH GLAND. × 425.

The reticular fibres which form the framework of both these tissues are difficult to see unless treated with special stains. In this preparation they are partially covered by the reticular cells which wrap round them. The cytoplasm of these cells is almost indistinguishable from the fibres though the nuclei stand out clearly. In the meshes of the tissues are free nucleated cells of two principal types: the histiocytes which are similar to those cells which enwrap the fibres, and the lymphocytes. These latter can be recognized easily by their darkly staining spherical nuclei. Where they are present in large numbers between the fibres they constitute the lymphoid tissue. Some monocytes also may be seen in this tissue. Small masses of lymphoid tissue in which the central cells are continually dividing to form new lymphocytes are called lymph nodules. Their appearance may be studied in the drawings of a lymph gland (page 180) and of the small intestine (page 190).

Fig. 25

RED BONE MARROW. × 340.

This tissue shows numerous cells of various types massed together. The smaller nucleated cells are the developing granular leucocytes (with lobed or kidney-shaped nuclei) and their precursors the myelocytes (with rounder nuclei). A few much larger cells with highly lobulated or ring-shaped nuclei are the giant cells. The fat cells show as clear oval or rounded spaces, the fat having been dissolved during preparation. The cells and fibres of the reticular tissue framework are difficult to distinguish. There are numerous blood vessels running through the tissue. The capillary sinusoids are filled with red blood corpuscles in various stages of development. Since the mature red corpuscles have no nuclei they stand out as lighter than the extravascular nucleated cells. In places the endothelium of the sinusoid walls can be seen.


RETICULAR TISSUE
Reticular Fibres
Reticular Cell
Lymph Spaces
Lymphocytes
Free Histiocyte
LYMPHOID TISSUE
Lymphocytes
Monocyte
Sinusoid Filled with Developing Red Corpuscles
Endothelium of Sinusoid Wall
Developing White Corpuscles
Giant Cell
Arteriole
Fat Cell

CHAPTER V

CARTILAGE AND BONE

An account of the various cartilage and bone tissues, and of the development of bone by the processes of ossification.

THE CARTILAGES

THE cartilages are the tissues that are commonly called gristle. They are found in the structure of certain organs and in close association with bone in the formation of the skeleton, giving support and in some cases protection to the softer tissues. The cartilages are

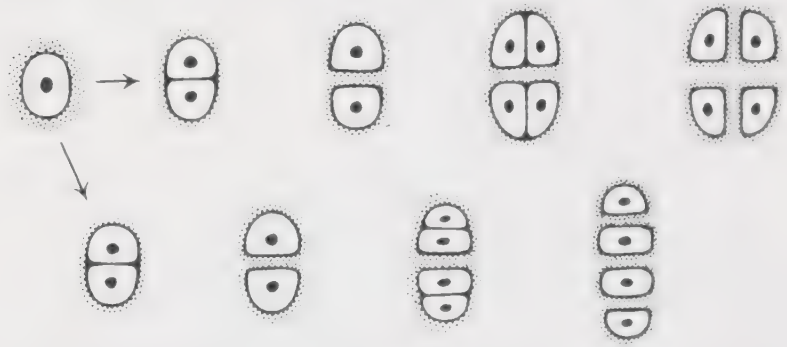


Fig. 26

DIAGRAM TO SHOW THE DEVELOPMENT OF CARTILAGE CELL GROUPS BY REPEATED MITOSIS

dense tissues of considerable firmness, yet possessing flexibility and marked resilience.

Like the other connective tissues, cartilage consists of a ground substance in which the cells lie embedded. The cartilage cells are large and rounded, with spherical nuclei. They occupy distinct lacunæ in the matrix, and although they are related to the other typical connective tissue

corpuscles they have no communicating branches. The cells are responsible for the formation of the intercellular substance. They divide by mitosis so that groups of cells are formed, which become dispersed as fresh matrix is laid down between the individual cells. Each cell is surrounded by a capsule of more recently formed dense matrix.

The matrix is a dense gelatinous substance, composed largely of a protein, chondrin. It is responsible for the physical properties of the cartilage tissues, and enables them to withstand considerable degrees of compression, torsion and tensile strain. The matrix may contain collagenous or elastic fibres: these increase the resistive powers and the elasticity of the tissues respectively, and adapt them to the mechanical requirements of different positions in the body. The fibrous content of the matrix is utilized as a means of classification into three types: hyaline cartilage, fibro-cartilage and elastic cartilage.

Hyaline Cartilage

Hyaline cartilage is a translucent, bluish-white tissue. It can be seen as a smooth and shining expansion on the articular surfaces of bones. It has a clear matrix, which contains no visible fibres, although a dense collagenous network is present. The cartilage cells, each surrounded by a well-marked capsule, are scattered, singly and in groups, throughout the matrix. Towards the surface of the tissue the cells are smaller and more flattened, and the groups are few. In the deeper parts the cells are larger and more spherical, though their adjacent borders may be flattened where they lie in close contact with each other in irregular groups or chains.

This tissue forms the temporary cartilage of the skeletal system. The majority of the bones of the adult skeleton are preceded, in the fœtus, by cartilage structures. The cartilage, being resilient, is more adaptable than bone and less liable to fracture; also it is capable of growth. The

cartilage is gradually replaced by bone through the processes of ossification, as the greater strength and the more rigid properties of bone are required. Growth ceases when the replacement by bone is complete.

In fully ossified bones hyaline cartilage persists as a covering on the articular surfaces. These articular cartilages function as shock absorbers, and their highly polished surfaces allow smooth movement of the joints. The effects of friction are repaired by continual slight growth of the cartilage.

The costal cartilages, which attach the anterior ends of the upper ten pairs of ribs to the sternum, are composed of hyaline cartilage. These structures increase the mobility and elasticity of the thorax. This is especially important in the movements of respiration. The lower two pairs of ribs are unattached in front, and are only tipped by hyaline cartilage.

Hyaline cartilage enters into the structure of the respiratory passages, keeping them open without interfering with their mobility. In the trachea and bronchi the cartilages are arranged in the form of incomplete rings, but in the bronchioles only small plates of cartilage are present. Hyaline cartilage also forms the firm but resilient walls of the larynx, and stiffens the tip of the nose.

With increasing age hyaline cartilage tends to become fibrous, or even calcified, and loses much of its resilience. These changes are especially marked in the cartilages of the larynx and the ribs.

Fibro-Cartilage

Fibro-cartilage is characterized by dense masses of unbranching white fibres lying in bundles in the matrix. The cells are few and are present in rows or small groups between the bundles of fibres. This tissue is exceedingly dense, tough and resistant to stretching; it is much less flexible and resilient than hyaline cartilage.

Fibro-cartilage is found exclusively in connection with the skeleton, forming structures continuous with the bones which, though as tough as the bone itself, offer the advantage of slight flexibility.

The bony spinal column is jointed from the sacrum to the skull to allow movement. There is a circular pad of fibro-cartilage interposed between each adjacent vertebra. These are firmly attached to hyaline cartilage plates on the opposing surfaces of the vertebral bodies. At the periphery of each disc the fibres have a circular arrangement, and the cartilage is very dense: towards the centre the tissue is soft and pulpy, due to a more fluid matrix and fewer fibres. Each disc is capable of limited compression or torsion and allows of a small amount of movement between adjacent vertebræ. The range of movement, however, is strongly limited by the densely massed fibres at the edges of the discs. The flexibility of the spine as a whole is due to summation of movement at all the intervertebral joints. The discs act also as shock absorbers, preventing undue jarring of the spine and head.

Other joints united by fibro-cartilage include the articulation of the ilium with the sacrum and the symphysis of the two pubic bones. The cartilage makes these joints extremely firm while permitting a very slight range of movement.

In certain freely movable joints, discs or wedges of fibro-cartilage lie in the joint cavity between the articular surfaces. They are attached at their peripheries to the lining of the capsule or to the edges of the bones. They serve as buffer structures, and in some cases make the two articular surfaces more compatible in shape. Complete discs are found in the sterno-clavicular and temporo-mandibular joints. In the wrist joint a small disc separates the distal end of the ulna from the carpal bones; while in the knee joint there are two horseshoe-shaped cartilages, called menisci.

The shoulder and hip joints are ball and socket joints, which allow wide ranges of movement. In each case the socket is deepened for greater security by a lip of fibrocartilage; this being slightly compressible does not interfere too greatly with the movements of the joint.

Elastic Cartilage

Elastic cartilage is a more flexible and resilient tissue than either of the other cartilages. Its elasticity is due to the dense network of elastic fibres in its matrix. The cells lie in small groups (between the fibres) surrounded by capsules of clear matrix.

This cartilage is found in only a few parts of the body. It strengthens the pinna of the ear, forms the epiglottis and parts of the larynx.

Perichondrium

Except on articular surfaces the cartilage structures are invested by fibrous tissue. This sheath, or perichondrium, blends with the cartilage so that there is no distinct line of demarcation between the two tissues. In the transition zone many fibres from the perichondrium penetrate into the cartilage matrix, and the cells may be considered to be intermediate between cartilage cells and fibrocytes. The perichondrium contains the blood vessels which supply the cartilage. Since the cartilage in most positions is avascular it has to depend on diffusion through its matrix for the exchange of materials between its cells and the blood vessels in the ensheathing membrane. The larger masses of cartilage do, however, contain some vascular channels.

BONE

Bone is one of the hardest materials of the body. It is closely related to the dentine of the teeth and these two tissues are exceeded in hardness only by the dental enamel.

The rigidity of bone is due to the inorganic salts, mainly calcium phosphate, with which the entire intercellular material is impregnated. When a bone is treated with dilute mineral acid the salts are removed and 50–70 per cent. of the weight of the bone is lost. The remaining organic materials retain the exact form of the original bone but have the flexibility and resilience of cartilage. It is this blending of the organic and inorganic materials in the structure of bones that is responsible for their great strength, combining rigidity with toughness and slight resilience.

Bone tissue is pervaded by vascular canals and spaces, around which the matrix is arranged in closely opposed sheets, or lamellæ. The bone cells, or osteocytes, are flattened oval bodies with finely branching processes. These cells lie in slit-like lacunæ between the sheets of matrix, their processes occupying tiny canaliculi which penetrate the lamellæ. The processes of certain of the cells have direct access to the vascular canals, and as the processes of all cells contact their neighbours a system of communicating canaliculi is set up throughout the matrix. It is by diffusion along these channels that the cells effect their exchanges of material with the blood: diffusion through the matrix itself is prevented by the presence of the inorganic salts.

In the structure of each bone there are two varieties of bone tissue. The outer layers are formed of dense compact tissue, while in the interior there is a much lighter cancellous tissue.

Compact Tissue

Compact tissue is dense, heavy and extremely hard, due to its tightly packed systems of cell-containing matrix. The blood vessels occupy small tube-like spaces termed Haversian canals. These canals lie roughly parallel to the long axis of the bone, but communicate with each other at

intervals. Each contains an artery, a vein, a lymphatic vessel and several nerve fibres supported in a small amount of reticular tissue. Each canal is surrounded by several

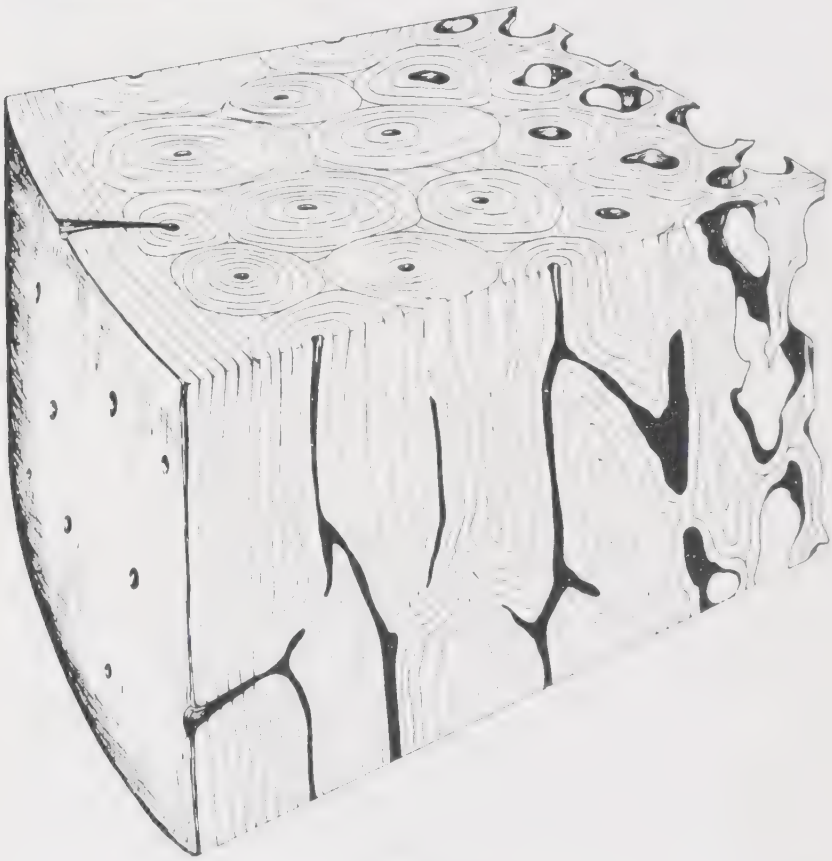


Fig. 27

DIAGRAM OF A BLOCK OF BONE SHOWING ITS LAMELLATED STRUCTURE, AND THE TRANSITION FROM THE BONE SURFACE (ON THE LEFT) THROUGH THE COMPACT TO THE CANCELLOUS TISSUE (ON THE RIGHT)

concentrically arranged lamellæ forming a cylindrical block of bone called a Haversian system. The bone cells of a Haversian system communicate with each other and with the central canal, but there is little contact between

the peripheral cells of the adjacent systems. Between the Haversian systems there are irregularly placed interstitial lamellæ. Directly beneath the periosteum there are four or five continuous lamellæ which encircle the whole bone. These subperiosteal lamellæ are especially hard and strong. Adjacent lamellæ are united by fibres of the organic matrix which pass from one to the other. The subperiosteal lamellæ are pierced also by large fibres from the periosteum.

The blood vessels from the periosteum enter the compact tissue through numerous small canals, which penetrate the subperiosteal lamellæ and link up with the Haversian canals. These Volkmann's canals are larger than the Haversian canals and have no surrounding concentric lamellæ.

Cancellous Tissue

Cancellous bone is light and porous. It contains numerous large intercommunicating spaces filled with bone marrow. The walls of these marrow spaces consist of irregular plates of bone, a few lamellæ only in thickness.

The cancellous tissue lies deep to the compact bone. There is a fairly abrupt transition from the one to the other due to the enlargement of the Haversian canals and a decrease in the number of their concentric lamellæ.

The blood vessels in the marrow spaces are branches of the nutrient artery which passes through the compact tissue. These vessels also link up with the arteries from the Haversian canals. Blood is drained from the marrow into the veins of the Haversian canals, and by other small veins which pass through the compact tissue and leave the bone close to the articular surfaces.

Functions of the Bone Tissues

The bones of the skeleton form a supporting framework for the body, protect its delicate organs, and assist in the

production of movement by providing leverage for the action of the muscles. The proportions of the compact

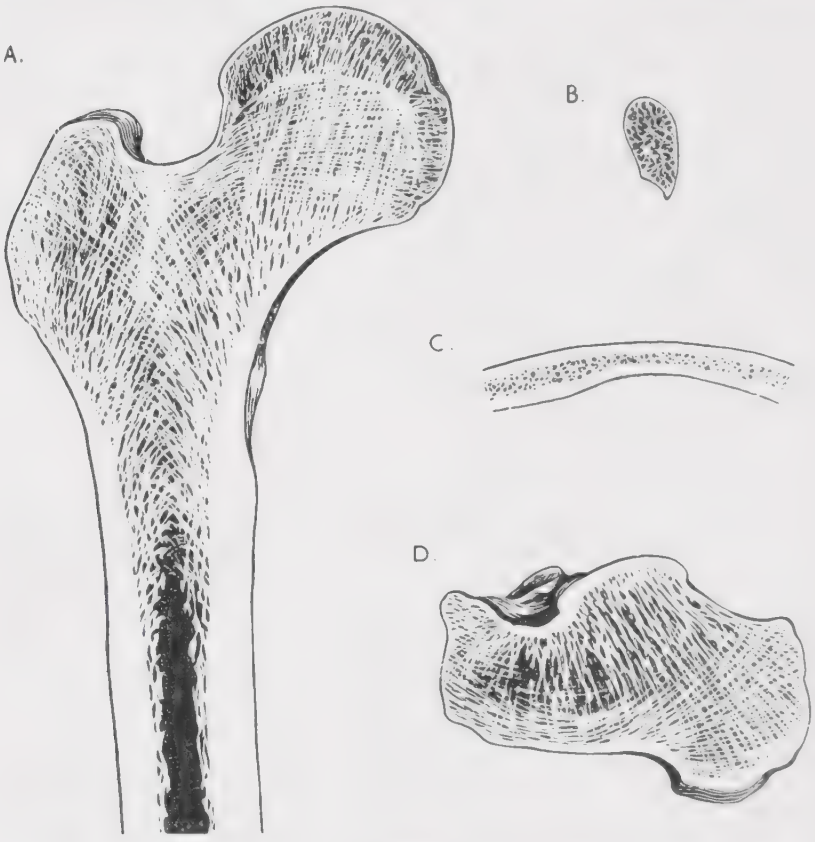


Fig. 28

DIAGRAM TO SHOW THE PROPORTION AND ARRANGEMENT OF THE COMPACT AND CANCELLOUS TISSUES IN VARIOUS BONES

A Longitudinal section of upper one-third of femur.
B Transverse section of a rib.
C Vertical section of parietal bone.
D Longitudinal section of calcaneus.

Note the stress lines indicated by the arrangement of the cancellous tissue.

and cancellous tissues vary according to the shape and size, and to the functions of the various bones.

The strength to resist externally applied forces, as well

as the habitual stresses produced by the weight of the body and the pull of muscles, is provided largely by the compact tissue. This also gives shape to the bone and affords a firm surface for the attachment of muscles through the medium of the periosteum. There is a greater thickness of compact tissue where extra strength is required, such as in the shafts of the long bones and in eminently protective bones such as those of the cranial cavity and the pelvis. The continual traction of muscles stimulates subperiosteal bone formation, so that the surfaces of a bone show tubercles and ridges, corresponding to the muscle attachments: these further increase the strength of the bone.

The cancellous tissue gives the necessary lightness to the bones. It is found, therefore, to be the constituent where lightness is essential, as in the enlarged extremities of long bones, or where resilience is needed, as in the ribs. In such positions it is covered by a very thin layer of compact bone. In the structure of protective bones the cancellous tissue acts as a shock absorber between the thick layers of compact tissue. The plates of the cancellous tissue are so organized that they help to withstand the stresses and tensions to which the bone is habitually subjected.

In addition to their mechanical functions the bones contain the body's store of calcium salts. As calcium is required for metabolic processes by many tissues it is important that its level in the blood and in the tissue fluids is kept constant. Any tendency for the calcium blood level to fall is remedied by the withdrawal of this mineral from the bones; while any excess calcium is laid down in the bone matrix by the agency of the osteocytes. The bones also have blood-forming and fat storage functions in virtue of their marrow content. These functions have already been discussed.

THE DEVELOPMENT OF BONES

The development of the skeletal system begins before birth and is not finally completed until about the twenty-fifth year of life. In the fœtus the future bones are represented by rods of hyaline cartilage or membranes of embryonic connective tissue. These structures are gradually replaced by bone as ossification proceeds.

There are two types of ossification. The development of bone in embryonic connective tissue by intramembranous ossification is the simpler process, as the bone is laid down directly in the existing tissue. The mandible and the flat bones of the cranial cavity are examples of the comparatively few bones which are formed by intramembranous ossification. The bones which are preceded by cartilage structures develop by intracartilaginous ossification. This is a complicated series of processes involving the complete destruction of the cartilage and its replacement by bone tissue. The majority of bones are formed in this way and they are sometimes referred to as cartilage bones.

Intramembranous Ossification

Embryonic connective tissue consists of undifferentiated cells and collagenous fibres in a gelatinous matrix. Prior to the commencement of ossification there is a great increase in the vascularity of the membrane tissue. The first changes are localized to one part of the membrane termed the primary centre of ossification; from here bone formation spreads towards the periphery. Any centres of activity which develop later are termed secondary centres.

At the centre of ossification radiating bundles of fibres called osteogenic fibres appear: these, accompanied by cells, grow outwards, penetrating the tissue between the blood vessels. The cells divide rapidly and assume bone-forming functions. These cells, now termed osteoblasts, form the

organic substance of the bone matrix along the course of the fibre bundles, which later become impregnated with calcium salts, so completing their conversion into minute spicules of bone. During the process some of the osteoblasts become surrounded by the calcified matrix and remain there as the cells of the bone tissue.

In this way a network of bone is gradually formed, containing in its meshes blood vessels and connective tissue rich in osteoblasts.

By the continued activity of the osteoblasts new layers of bone are deposited on the existing surfaces, gradually thickening the network and encroaching on the vascular spaces. Near the surface of the membrane the deposition of successive lamellæ continues, and the compact tissue is gradually formed by the conversion of the vascular spaces into Haversian canals. Internally multinucleate giant cells, or osteoclasts, absorb the bone tissue almost as quickly as it is formed, so that the tissue retains its cancellous nature. These cells are especially important in the remodelling of the bone which is continually taking place as the structure grows.

As the conversion from connective tissue to bone proceeds outwards the edges of the membrane continue to grow, so that by the time ossification is complete the full size of the bone has been reached. The original membrane becomes transformed into the periosteum, as the bone develops inside it. New surface layers are continually laid down beneath the periosteum, and as the bone increases in thickness there is a corresponding absorption of bone from the internal layers.

Intracartilaginous Ossification

Before the first changes take place within the cartilage a thin shell of bone is laid down on its surface by the osteoblasts in the surrounding membrane, by a process similar to that of intramembranous ossification. This is

known as perichondrial ossification. It is also from the surrounding membrane that the blood vessels of the future bone and the osteogenic elements responsible for its formation are derived. The changes which occur within the cartilage itself are termed endochondrial or intracartilaginous ossification. They may be divided into three phases.

1. *Phase of Hypertrophy*

At the centre of ossification in the depths of the cartilage rapid growth takes place. The cells divide repeatedly, forming long radiating rows. Later the central cells become large and spherical, separated from each other only by thin walls of cartilage matrix. Calcium salts, from the blood in the surrounding vessels, diffuse into the cartilage and become deposited in the matrix. This prevents the normal exchange of material between the cartilage cells and the blood, so that the cells, now completely imprisoned, gradually shrivel and die leaving the centre of the cartilage honeycombed by large empty spaces, termed primary areolæ.

2. *Phase of Irruption*

During this phase the capillaries from the surrounding membrane break their way through the subperiosteal bone at several points and proceed to absorb the calcified cartilage matrix, possibly by the action of enzymes. By the destruction of their thin walls the primary areolæ are converted into large irregular secondary areolæ, into which project jagged spikes of calcified cartilage.

3. *Phase of Calcification*

Following the irruption through the external bone shell there is an ingrowth of periosteal tissue. Osteogenic fibres, osteoblasts and blood vessels penetrate into the secondary areolæ and with their advent the formation of true bone is

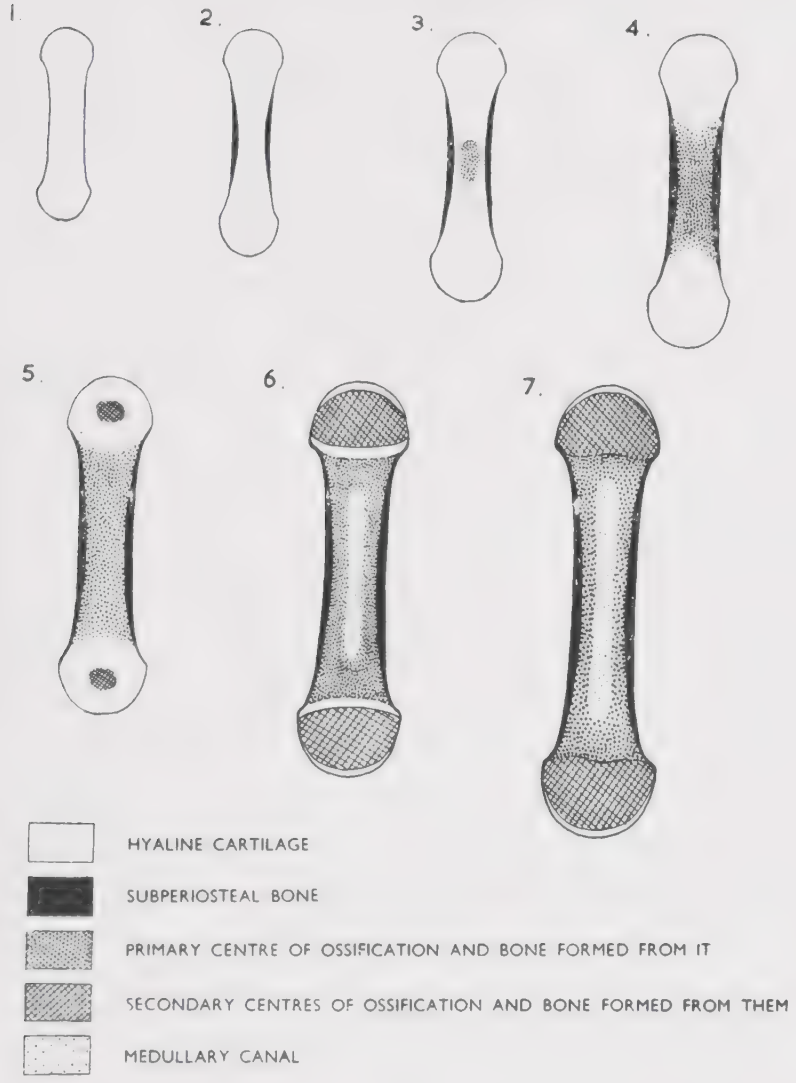


Fig. 29

DIAGRAM SHOWING THE STAGES IN THE DEVELOPMENT OF A LONG BONE

1–4. Pre-natal development.
5–7. Post-natal development.

begun. The osteoblasts become arranged around the projections of calcified cartilage and bone is laid down on the surfaces. Simultaneously there is a further absorption of the remaining calcified cartilage matrix, so that gradually the cartilage is entirely removed and replaced by irregular trabeculæ of bone. The formation of the bone tissue now proceeds, as in intramembranous ossification, with the continual addition of new lamellæ and the gradual conversion of the secondary areolæ into the vascular spaces and the Haversian canals of the cancellous and compact bone. There is continual destruction and remodelling of the bone tissues, allowing for changes of shape as the bone grows.

These changes continue in ordered sequence throughout the cartilage so that in a microscope preparation of a developing cartilage bone distinct zones can be seen, corresponding to the three phases of ossification. In almost all cartilage bones ossification is initiated from more than one centre. There is an eventual fusion of the bone formed from the primary and secondary centres, with the final obliteration of all the hyaline cartilage except on the articular surfaces. The growth of cartilage bones occurs during the period of ossification. In the long bones an increase in length is due to growth of the unossified cartilage. The last cartilage to be replaced are thin plates, termed epiphyseal plates, separating the bone of the extremities from that of the shaft. With ossification of these cartilages growth ceases. Growth in diameter is due to the continual laying down of bone beneath the periosteum.

Factors affecting Ossification

The processes of bone growth and ossification are regulated by hormones, notably the growth hormone of the anterior pituitary gland and the hormone of the parathyroid glands. The action of these hormones is to carry

out what is thought to be an inherited "growth pattern," characteristic of man, in which the different bones and the skeleton as a whole develops in a predetermined manner, but which none the less allows for variations in speed and final extent of growth according to individual inheritance. This pattern is, however, influenced markedly by environmental factors. Diet plays an important part supplying the materials essential to the formation of bone tissue. These include minerals, particularly calcium and phosphorus, for the formation of the hard inorganic matrix: vitamin D which is essential for the utilization of the calcium and phosphorus: proteins and vitamin C for the formation of the organic matrix, and vitamin A which appears to be essential to all tissue growth. Not only must a child's diet from birth contain a sufficiency of all these materials but, since ossification occurs rapidly before birth, the mother's diet during pregnancy must be rich enough to supply to developing fœtus. Since vitamin D can be manufactured in the body by the action of ultraviolet rays on the skin, sunlight is an important factor in bone development. In addition, exercise, a sufficiency of energy-giving foods, adequate rest and general healthy conditions all contribute to good bone formation. Disease retards and may actually stop ossification temporarily.

Even when the full size of a bone is attained and ossification is complete there is continual remodelling of the bone tissues and replacement of material. Following a fracture new bone tissue is laid down rapidly by subperiosteal ossification at the site of the break forming a splinting structure. Then by the combined action of the osteoblasts and osteoclasts the bone is remodelled and excess material is removed.

Fig. 30

HYALINE CARTILAGE OF THE TRACHEA. 205.

The oval and rounded cartilage cells are arranged principally in groups as they have been formed by mitosis. Where they lie in close contact with each other they are flattened by mutual compression. A few single cells may be seen. In some places the cells have shrunk considerably inside their lacunæ leaving spaces which are not present during life. The matrix between the cells is clear and no fibres are visible. The capsules of newly formed matrix round the cells are stained more darkly. In the upper part of the drawing the transition to the surrounding fibrous tissue is shown. Here the cells are more often arranged singly and become progressively smaller and more flattened towards the fibrous tissue. The matrix between these cells may contain some white fibres.

Fig. 31

WHITE FIBRO-CARTILAGE OF AN INTERVERTEBRAL DISC. × 90.

The main constituents of this tissue are the densely massed white fibres, arranged in bundles which lie roughly parallel to each other. Between the bundles are the small, rounded or oval cartilage cells, often lying in rows or in pairs as they have been formed by mitosis. They are surrounded by clear matrix capsules free of fibres.

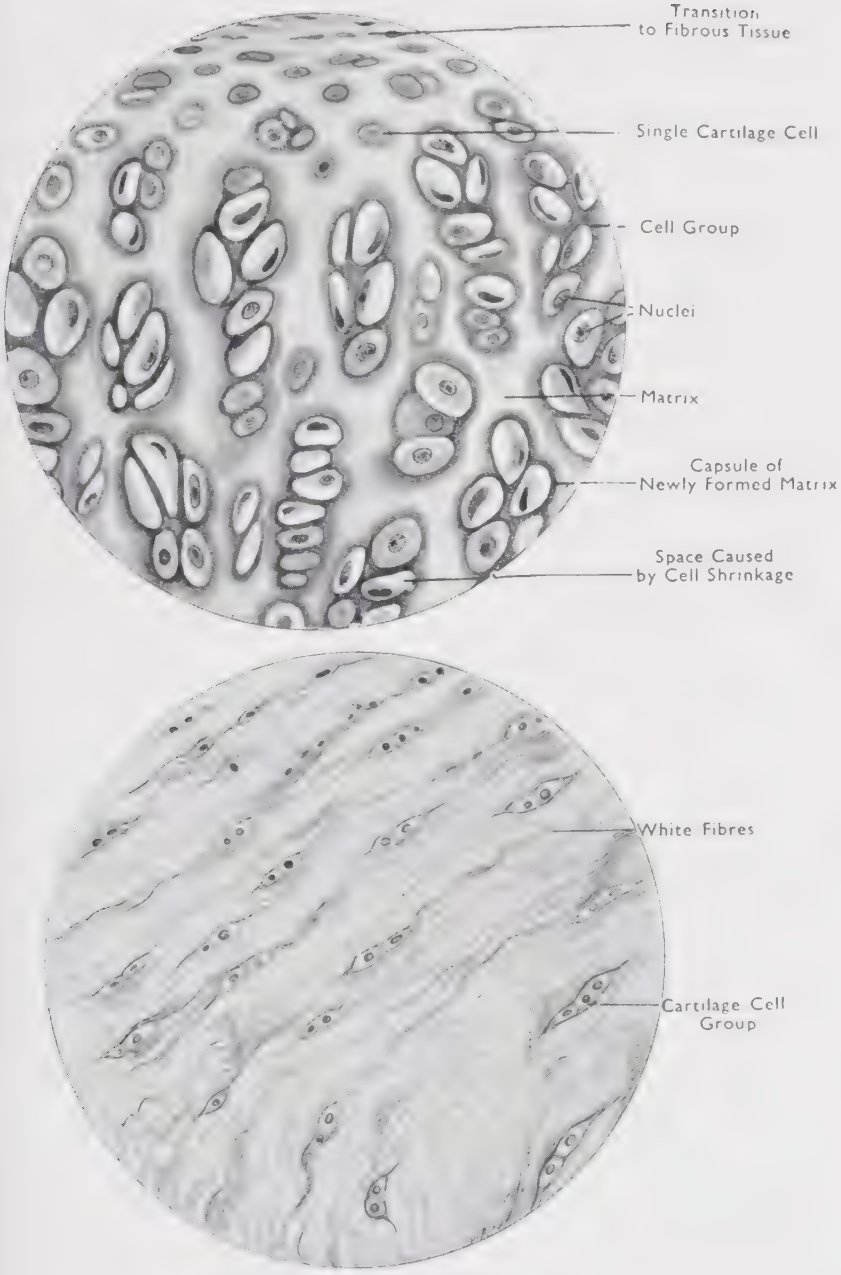

Transition
to Fibrous Tissue
Single Cartilage Cell
Cell Group
Nuclei
Matrix
Capsule of
Newly Formed Matrix
Space Caused
by Cell Shrinkage
White Fibres
Cartilage Cell
Group

Fig. 32

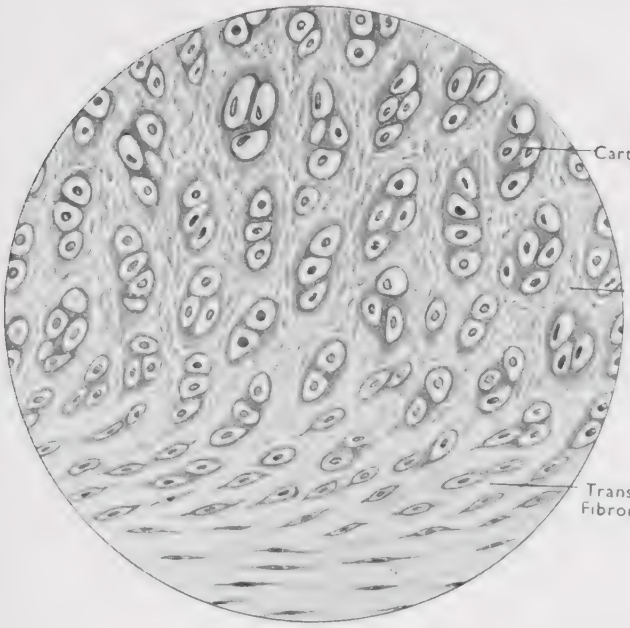
YELLOW ELASTIC CARTILAGE OF THE PINNA OF THE EAR. × 175.

In this tissue the cartilage cells lie in groups more like those of hyaline cartilage. Around each group is a small amount of clear matrix. In other parts the matrix is pervaded by a dense, branching arrangement of elastic fibres. In this preparation the fibres show as clear unstained threads appearing lighter than the supporting matrix: the fibres may, however, be stained so that they stand out darkly. The transition from the cartilage to the perichondrium is shown in the lower part of the drawing; the cells becoming progressively smaller and more flattened, and the matrix containing an increasing number of white fibres.

Fig. 33

COMPACT BONE TISSUE. TRANSVERSE SECTION. × 175.

This type of section is made by grinding a block of the compact bone down to a wafer, which is sufficiently thin to allow light to penetrate it easily. This method destroys the cells and the contents of the canals, but the bone dust which collects in their stead appears dark and serves to demonstrate the original positions and shapes of the cells and the vascular canals. The Haversian canals, cut transversely, are each surrounded by concentrically placed lamellæ of bone matrix, forming the Haversian systems. Between these systems are the interstitial lamellæ, while several subperiosteal lamellæ form the outer boundary of the tissue. One of the Volkmann's canals, which pierce the subperiosteal lamellæ to link up with the Haversian canals, is shown here. The lacunæ, which in life lodge the bone cells, are seen between the various lamellæ. The canaliculi, radiating from them, penetrate the lamellæ, so linking up the lacunæ with the Haversian canals.


Cartilage Cell Group
Elastic Fibres in Matrix
Transition to Fibrous Tissue

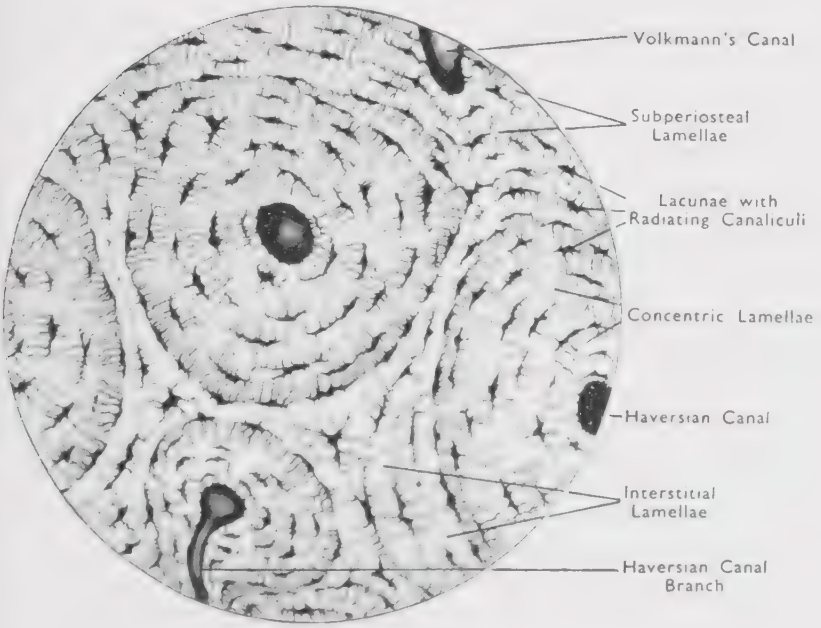

Volkmann's Canal
Subperiosteal Lamellae
Lacunae with Radiating Canaliculi
Concentric Lamellae
Haversian Canal
Interstitial Lamellae
Haversian Canal Branch

Fig. 34

COMPACT BONE TISSUE. LONGITUDINAL SECTION. × 110.

This also is a ground preparation, but in this case the section is made parallel to the principal Haversian canals. Since these canals are not perfectly straight they do not lie in the plane of the section for their full length. A Volkmann's canal piercing the subperiosteal lamellæ is shown also. It is more difficult to distinguish between the different lamellæ since, whatever their arrangement as seen in transverse section, they all appear parallel in longitudinal section. Those nearest the bone surface are the subperiosteal lamellæ: those close to the Haversian canals are the concentric lamellæ, while those which are more widely spaced are the interstitial lamellæ. The lacunæ, canaliculi and canals contain bone dust as in the previous preparation.

Fig. 35

CANCELLOUS BONE TISSUE. TRANSVERSE SECTION. × 80.

In this preparation the section was made from a piece of bone which previously had been decalcified. This method preserves the cells and the contents of the marrow spaces, and allows of the staining of the tissue. The spikes or plates of cancellous bone consist of two or three lamellæ between which the bone cells can be seen as darker dots. These bone plates surround large marrow spaces which communicate frequently so that the tissue is irregular in arrangement. The bone marrow in these spaces is indicated but not shown in detail. Nearer to the compact tissue the spaces are smaller and more regular and the intervening bone is thicker, being formed of more numerous lamellæ.

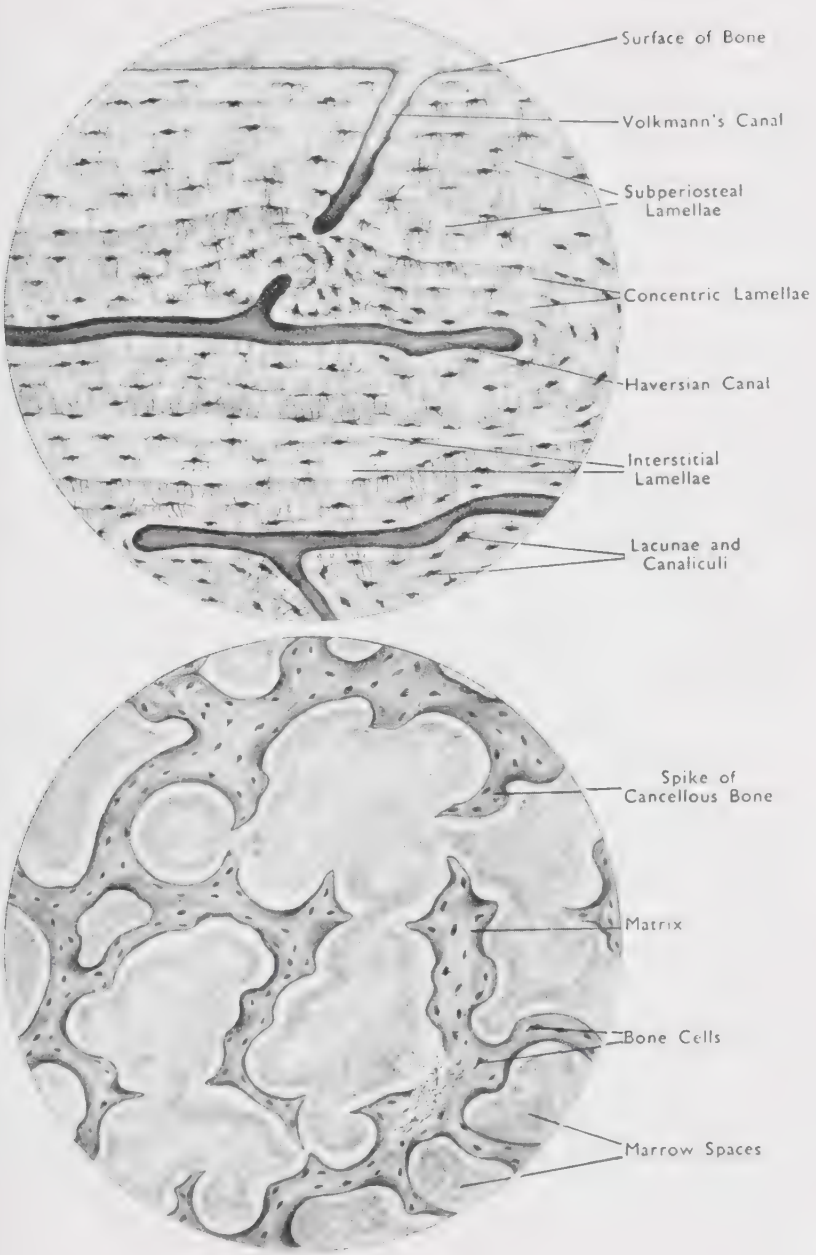

Surface of Bone
Volkmann's Canal
Subperiosteal Lamellae
Concentric Lamellae
Haversian Canal
Interstitial Lamellae
Lacunae and Canaliculi
Spike of Cancellous Bone
Matrix
Bone Cells
Marrow Spaces

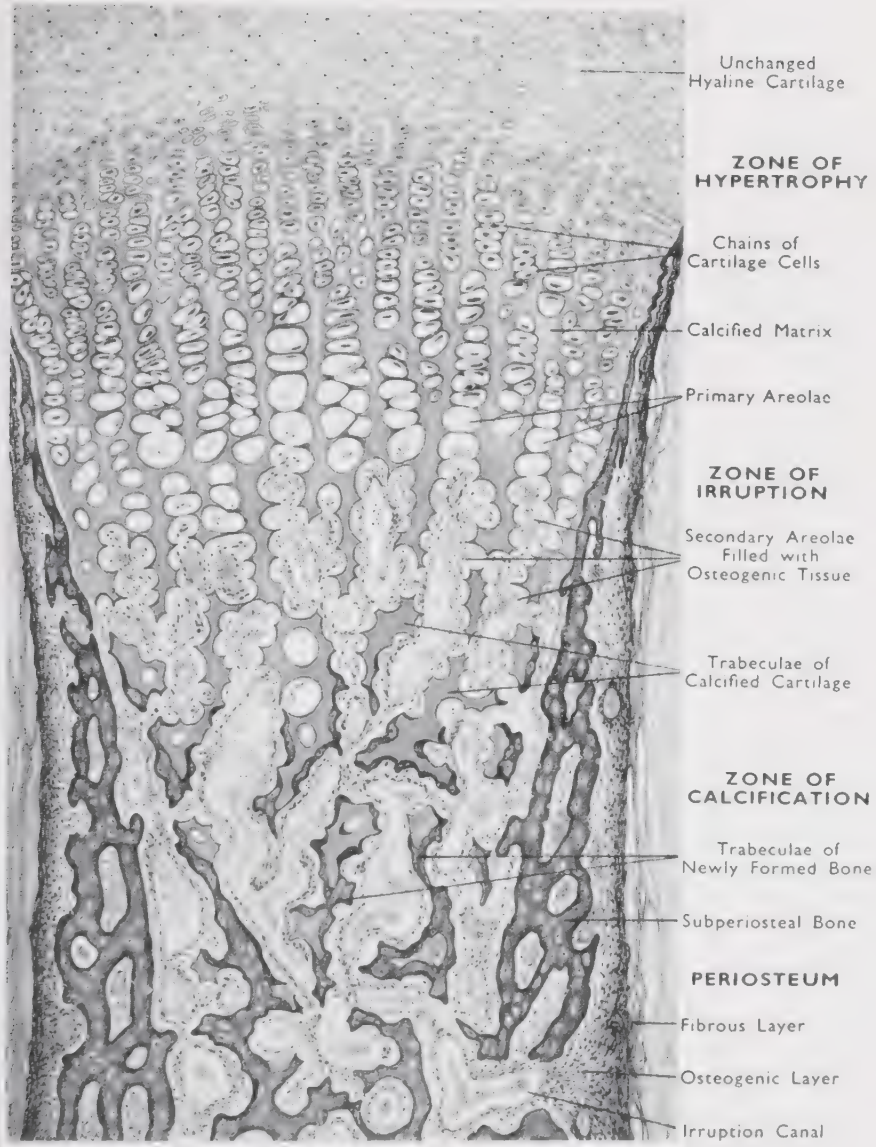
Fig. 36

DEVELOPING LONG BONE. LONGITUDINAL SECTION. × 85.

The various stages of intracartilaginous ossification are shown as they appear in a partially ossified phalanx. The whole structure is invested by the periosteum which is seen to consist of a dense fibrous outer layer, and a looser inner layer containing numerous small cells, the osteoblasts. At the top of the drawing, part of an epiphysis of hyaline cartilage can be seen. Nearer to the shaft, the matrix between the cartilage cells appears darker due to the accumulation of calcareous deposits. The cells themselves are larger and more numerous. The arrangement of these cells in vertical rows indicates their earlier formation by repeated mitosis. These features become progressively more marked until the cells, imprisoned in completely calcified matrix, have shrunk and died, so forming the primary areolæ. These changes in the cartilage structure take place during the phase of hypertrophy. The calcified cartilage is separated from the periosteum by a thin layer of subperiosteal bone.

Below this region the tissue appears looser. This represents the phase of irruption. The larger and more irregular secondary areolæ have been formed by the destruction of the thin walls between the primary areolæ, leaving only a few irregular spikes of calcified cartilage. The secondary areolæ are filled with osteogenic tissue, containing numerous osteoblasts and blood vessels. This zone is completely enclosed by a thick layer of subperiosteal bone.

The phase of calcification is represented by the zone nearest the bottom of the drawing. Here the cartilage spikes are being gradually converted into bone: the darker bone layers can be seen at the surfaces of the cartilage. Some completely ossified trabeculæ are shown and these, in places, are continuous with the surrounding subperiosteal bone. This outer layer of bone is here considerably thickened and shows a primitive type of compact structure. A large canal passing through the subperiosteal bone connects the secondary areolæ with the periosteum, and marks one of the sites of original irruption. This canal will be retained in the fully ossified bone as a nutrient foramen.


Unchanged
Hyaline Cartilage
ZONE OF
HYPERTROPHY
Chains of
Cartilage Cells
Calcified Matrix
Primary Areolae
ZONE OF
IRRUPTION
Secondary Areolae
Filled with
Osteogenic Tissue
Trabeculae of
Calcified Cartilage
ZONE OF
CALCIFICATION
Trabeculae of
Newly Formed Bone
Subperiosteal Bone
PERIOSTEUM
Fibrous Layer
Osteogenic Layer
Irruption Canal

CHAPTER VI

BLOOD AND THE TISSUE FLUIDS

The structure and functions of the blood, and of the tissue fluid, the lymph and the cerebro-spinal fluid which are derived from the blood.

BLOOD is a fluid tissue belonging to the connective tissue group. Throughout life it is kept in continual circulation through the blood vessels by the pumping action of the heart. In this way it acts as a transporting medium, conveying to the millions of cells in the body the materials essential to their life processes, and removing from them some of the products of their metabolism, for excretion or for use in other parts. It is in the capillary vessels that the blood comes into closest contact with the extravascular tissues; but even so it is, in most cases, separated from them by the endothelium of the capillary walls. The blood, however, gives rise to a fluid which bathes the cells of the tissues and acts as an intermediary for exchange of material between them and the blood. Under the name of lymph this fluid is drained from the tissues by a system of converging vessels which eventually pass it back into the venous blood stream. In addition to their distributive functions the blood and the tissue fluids have anti-infective properties which help to protect the body from disease.

THE STRUCTURE AND COMPOSITION OF THE BLOOD

Blood is a red, opaque and somewhat viscid fluid. To the naked eye it appears to be of homogeneous consistency, but in fact it consists of millions of tiny

corpuscles suspended in a liquid matrix called the plasma.

The Corpuscles

The solid structures of the blood are the red blood corpuscles or erythrocytes, the white blood corpuscles or leucocytes and the blood platelets.

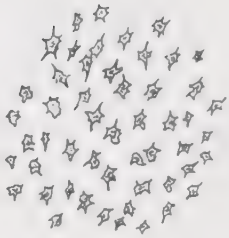
The Red Corpuscles

The red blood corpuscles are minute non-nucleated bodies, approximately 7μ in diameter and shaped as circular biconcave discs. There are about five million of these cells in every cubic millimetre of blood. In certain inflammatory conditions and when the blood is shed the red corpuscles lie on top of each other in piles or rouleaux.

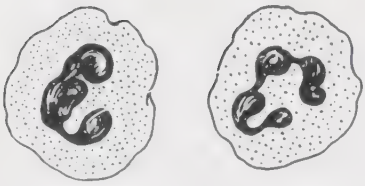
Each corpuscle is enclosed in a fine elastic membrane of lipide and protein material, and contains hæmoglobin and inorganic salts dissolved in water. The hæmogoblin is a compound of a protein, globin, and an iron-containing pigment called hæmatin. It combines readily with oxygen to form an unstable compound, oxyhæmoglobin, from which the oxygen is equally readily given up when required. The pigment of the hæmoglobin is responsible for the colour of the blood, though the individual cells have only a faint orange tinge. Oxyhæmoglobin is a brighter red than reduced hæmoglobin and this accounts for the difference in the colour of arterial and venous blood. Hæmoglobin combines also, but to a lesser extent, with carbon dioxide.

The red blood corpuscles are formed in the capillary sinusoids of the red bone marrow. During their formation the sinusoid is temporarily occluded by constriction at either end. Meanwhile the reticulo-endothelial cells which form the incomplete walls give rise to free nucleated cells. These cells pass through various stages of development

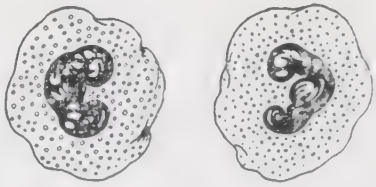
RED CORPUSCLES



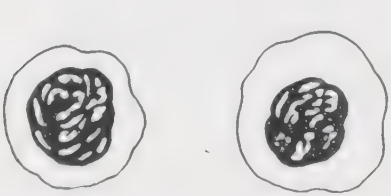
PLATELETS



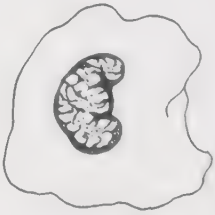
TWO NEUTROPHIL GRANULOCYTES
(POLYMORPHONUCLEAR LEUCOCYTES)



BASOPHIL AND OXYPHIL
GRANULOCYTES



SMALL AND LARGE LYMPHOCYTE



MONOCYTE

Fig. 37

DIAGRAM OF THE CELLS OF THE BLOOD

including further division, the accumulation of hæmoglobin and finally the extrusion of their nuclei. The sinusoid then opens and the fully mature red cells pass into general circulation. The formation of the red cells is continuous throughout life. It is increased as a result of loss of blood, and in conditions in which the oxygen tension in the blood is lowered over a period of time. Before birth the red cells are formed in the first place in isolated blood islands, and later in both the spleen and the liver.

Although the red corpuscles are deprived of their nuclei before they enter the circulation it is estimated that they can exist for as long as fourteen to seventeen weeks, after which fragmentation occurs and the particles are ingested by the phagocytic cells of the reticulo-endothelial system.

The White Corpuscles

The white blood corpuscles are colourless, nucleated cells, somewhat irregular in shape. Their total number, ranging between 5,000 and 10,000 in every cubic millimetre of blood, is comprised of several different types of cells. These may be classed in two groups—the granulocytes and the non-granular or lymph cells.

The neutrophil granulocytes or polymorphonuclear leucocytes are the most numerous of the white cells and represent from 65 to 75 per cent. of the total number. They have horseshoe-shaped or lobed nuclei and a finely granular cytoplasm. Other types of granular cells are the acidophil (oxyphil) and basophil granulocytes. These are comparatively few in number. Their nuclei are less irregular and their cytoplasm more coarsely granular than in the neutrophils. These three groups of cells are differentiated by the staining of the granules in their cytoplasm.

The non-granular cells are the lymphocytes and the

monocytes. The lymphocytes are the smallest type of white cell, being little larger than the red corpuscles. They have large, spherical, darkly staining nuclei surrounded by a little cytoplasm. They are the next most numerous to the polymorphs. Some larger sized lymphocytes are present also. The monocytes are the largest of all the white cells but they are relatively few in number. They have large spherical or kidney-shaped nuclei.

The granulocytes are formed from the myelocytes, in the extravascular spaces of the red marrow of the bones: (page 63). Some lymphocytes and monocytes may be formed in the red marrow also, but the main site of their production is in the germinal centres of the lymphoid tissue: (page 62).

The Blood Platelets

The blood platelets are tiny cell fragments containing granules which tend to clump centrally giving the appearance of a nucleus. The platelets readily disintegrate when they come into contact with a rough surface, particularly when blood is shed. On destruction they liberate an enzyme called thrombokinase which initiates the process of blood clotting. The number of platelets, estimated to be about 200,000 in every cubic millimetre of blood, is maintained by continual replacement from the red narrow, where they are shed from the giant cells: (page 63).

The Plasma

The plasma, in which the corpuscles are suspended, forms approximately half of the blood volume. It is a clear, pale yellow liquid composed mainly of water, but containing a great variety of dissolved substances as well as very small amounts of fat in finely emulsified form. The main constituents of the plasma, other than the water, are blood proteins, inorganic salts, nutrients, excretory

products, hormones, enzymes, antibodies and gases. Some of these substances are constant constituents, and any variation in concentration is rapidly readjusted: the levels of other substances fluctuate with the intake into the body or with the activity of the tissues.

The proteins are serum albumen, serum globulin and fibrinogen. They are peculiar to the blood itself and should not be confused with the nutritive materials of protein origin which also are present in the plasma. All the proteins help to maintain the osmotic pressure of the blood, and fibrinogen, in addition, plays an important part in blood clotting as it is the precursor of the fibrin which forms the clot. The blood enzymes also are protein in nature. These may be present in their active or their non-active pro-enzyme form. They are concerned with the chemical reactions which take place in the blood plasma.

Of the numerous inorganic salts sodium chloride is present in the largest quantity, and it is this which gives the blood its salty taste. Phosphates, carbonates and sulphates of sodium and calcium are also to be found in the plasma, and many other salts may be present in smaller amounts. Some of the inorganic salts are essential to the maintenance of the alkaline reaction of the blood or to various processes such as blood clotting; others represent nutritive materials or waste products which are being transported to or from the tissues.

The nutrient materials are amino acids, glucose, fatty substances, vitamins and certain of the mineral salts. The excretory products include urea, uric acid, creatinine and salts of various acids formed during cell metabolism. Carbon dioxide and water are added to the blood by all cells as excretory products of oxidation, but very little of the total amount of the carbon dioxide carried in the blood is in simple solution in the plasma. The other gases in the plasma are oxygen, in minute traces, and nitrogen. The latter is of no known value to the body.

THE REACTION OF THE BLOOD

The slightly alkaline reaction of the blood (pH 7·3–7·5) depends on a delicate balance between the acid and alkaline constituents of the plasma. This balance is maintained by various chemical adjustments known as "buffering" processes, and the substances, particularly salts, which by combining with excess acids or excess alkalies so reducing their effect on the blood reaction, are termed "buffer" substances.

Many of the excretory products added to the circulating blood are acids, so that a quantity of alkaline buffer salts must always be maintained in the plasma. This is known as the alkaline reserve of the blood. It is comprised mainly of sodium bicarbonate. Although the buffering of excess alkalies occurs to a lesser extent there is not the same need for a definite acid reserve.

As the reaction of the blood is affected only by materials in the plasma, the carriage by the blood corpuscles of certain substances such as oxygen and some carbon dioxide is sometimes termed primary buffering.

The buffering processes are of the greatest importance, as alterations in the reaction of the blood, and therefore of the tissue fluids, quickly affect the activity of the cells.

BLOOD CLOTTING

Although the blood is liquid under normal circulatory conditions, it tends to clot when it escapes from the blood vessels. The clot is formed by the deposition of threads of insoluble fibrin across the mouth of the cut vessel. This network enmeshes the blood cells and forms a soft plug, checking the further escape of blood and preventing the ingress of bacteria. Gradually the clot shrinks and exudes a clear liquid known as serum. The serum evaporates leaving the now solid clot firmly sealing the vessel.

The initiation of the clotting process appears to depend on the contact of the blood with a roughened surface, such as that provided by torn vessel walls and muscle fibres. When this occurs the fragile platelets get caught up in large numbers and quickly disintegrate. Their destruction sets free the enzyme thrombokinase, which probably is formed by the injured tissues as well. The thrombokinase in the presence of the calcium salts changes the prothrombin in the plasma to the active enzyme, thrombin. This in turn converts the fibrinogen into solid fibrin.

Thrombokinase is produced in small quantities at all times by the continuous though slight disintegration of platelets in the circulating blood. Its action, however, is opposed by an anticoagulant called heparin which is present in the plasma. Although the heparin is valuable in preventing clotting under normal conditions, it is ineffective against the large amounts of thrombokinase set free when injury occurs.

Moderate heat speeds up the enzyme action and therefore hastens clotting. Intense heat destroys the enzymes, but it coagulates the blood proteins so that a clot is formed without the assistance of enzyme action. Cold slows the process or, if sufficiently intense, will even prevent it by rendering the enzymes inactive.

The serum which is squeezed out as the clot shrinks differs from the plasma in that it contains both active thrombin and thrombokinase, but no fibrinogen.

THE FUNCTIONS OF THE BLOOD

The Carriage of Oxygen

Oxygen is needed by all the cells of the body for the production of energy. Its use results in the formation of carbon dioxide and water as excretory products. Oxygen is carried in comparatively large quantities by the red

corpuscles of the blood. As the blood passes through the capillaries of the lungs the oxygen diffuses from the alveolar air through the respiratory membrane into the plasma, and thence into the red corpuscles where it enters into chemical combination with the hæmoglobin. This diffusion is very rapid owing to the large respiratory surface and the equally large surface area presented by the millions of biconcave red cells. On leaving the lungs the blood is almost saturated with oxygen: every 100 c.c. contains 18–19 c.c. of oxygen, and of this only 0·7 c.c. is in simple solution in the plasma.

When the blood flows through the capillaries in tissues other than the lungs some of the oxygen diffuses out into the tissue fluid and the surrounding cells. The amount supplied to the tissues is variable and is directly related to their requirements. A low oxygen tension in a tissue encourages the diffusion of oxygen from the plasma and its dissociation from the hæmoglobin of the red cells. The rate of dissociation of oxygen is influenced also by the rate of production of carbon dioxide, since as this diffuses into the blood it helps to displace the oxygen from the red corpuscles. A rise in temperature also has the effect of hastening oxygen dissociation. All these conditions, conducive to a speedy diffusion of oxygen from the blood to the tissues, and of carbon dioxide in the opposite direction are produced by the activity of tissues. When the blood leaves the tissues the oxygen content has been reduced to 12–14 c.c. in every 100 c.c. of blood.

The Carriage of Carbon Dioxide

In every 100 c.c. of both oxygenated and reduced blood there is at least 52–54 c.c. of carbon dioxide always present. This is known as the constant carbon dioxide of the blood. It travels principally in the form of sodium bicarbonate, together with traces of carbonic acid (carbon dioxide in solution in water). The ratio between the alkaline

bicarbonate and the carbonic acid is about 20 : 1, and this is maintained as nearly as possible under varying conditions.

The carbon dioxide which is carried by the blood from the tissues to the lungs, where it is given up by diffusion to the alveolar air, is known as the mobile or excretory carbon dioxide. This mobile carbon dioxide forms an additional 4–8 c.c. in every 100 c.c. of reduced blood. Most of it passes immediately into the red corpuscles where it combines with the protein constituent of the hæmoglobin to form carbamino compounds. In the plasma some of the excess carbonic acid reacts with sodium salts forming additional sodium bicarbonate, so that the acid-base balance is maintained in spite of the increase of free carbonic acid.

A rise in the concentration of carbonic acid in the plasma has the effect of stimulating the respiratory and circulatory mechanisms, and so expediting its removal by the lungs. The carbonic acid level also rises when stronger acids, such as lactic acid, enter the blood as a result of tissue metabolism. They displace the carbon dioxide from the sodium bicarbonate, so that the stronger acid is buffered and the weaker carbonic acid travels freely. When this occurs the acid-base balance is lost temporarily, but is quickly restored as the excess acids are removed from the blood by excretion.

The Carriage of Nutritive Materials

The nutritive materials carried by the blood are glucose, traces of other simple sugars, amino acids, fats and other lipides, vitamins and mineral salts. These materials are taken into the body by absorption from the digestive tract, the water soluble nutrients passing directly into the blood, while the fatty materials enter the lymphatic endings in the intestinal villi (lacteals) and reach the blood by the lymph stream. Nutrients which are stored in the body are

passed into the blood stream from the storage organs as they are required.

From the blood the nutrients pass to the tissues by diffusion. Glucose and fats are taken into the cells to provide fuel for energy liberation. Amino acids are synthesized into proteins for the growth and repair of the tissues and for the formation of secretions. Mineral salts enter into the composition of various tissues and glandular secretions, and regulate many chemical and physical processes in the body. The vitamins act mainly as regulators of the metabolic processes of the cells. When the immediate requirements of the tissues have been satisfied, excess of certain foodstuffs may be removed from the blood for storage, while others are excreted.

The blood level of some of these foodstuffs tends to fluctuate on account of the intermittent intake and the varying requirements of the body. The concentration of other substances, notably glucose, are kept fairly steady by a balance between its addition to the blood from the alimentary canal or from body stores, and its removal by use, by storage or in some cases by excretion.

The Carriage of Waste Products

The products of cell metabolism enter the blood by diffusion from the tissues or by means of the lymph stream. The nature of these products varies; for instance the blood leaving vigorously working muscles carries creatinine, lactic acid and phosphoric acid, while the end products of protein metabolism, such as urea and uric acid, enter the blood as it flows through the liver. Carbon dioxide and water are formed by all cells as a result of oxidation.

As has already been explained, the acid waste products are carried in the blood largely in "buffered" form. The waste materials continue to circulate until they are removed or their level adjusted by the various organs of excretion.

The Carriage of Hormones

Hormones are secreted into the blood by the ductless glands. By circulating in the blood stream they are able to come into contact with all cells which are sensitive to them in widely separated parts of the body. Many hormones are constantly present in small amounts in the plasma, but their concentrations tend to vary from time to time with alterations in the activities of the glands. Other hormones are produced only as they are needed.

The Distribution of Heat

Another important blood function is the distribution of heat throughout the body. Heat is produced by the energy liberating processes of all cells, particularly in the glands and muscles. The blood flowing through these organs becomes heated, and in its turn supplies warmth to other cooler parts of the body. This not only prevents an excessive rise of temperature in the working tissues, but maintains an adequate temperature in the less active parts. The circulating blood allows also the loss of heat from all the surfaces of the body, particularly the skin. As the blood supply to the skin is adaptable, this heat loss can be regulated to meet variations in both external temperature conditions and internal heat production.

Anti-infective Functions

The white corpuscles are responsible for the protective properties of the blood. Invading bacteria are combated both by phagocytosis and by the secretion of anti-infective substances termed antibodies. The ingestion of bacteria is primarily the function of the polymorphonuclear leucocytes. These are assisted to some extent by the monocytes and by the histiocytes of the connective tissues. The monocytes act also as general scavengers of the blood,

keeping it clear of foreign material and particles of disintegrating cells.

The antibodies are secreted mainly by the lymphocytes. These substances include antitoxins, which counteract the toxins produced by the bacteria. Each toxin is met by the formation of a specific antitoxin. Some antitoxins disappear from the blood within a few weeks of the suppression of the infective agent; while others, once formed, persist and render the body immune to any further onslaught of that particular infection. Other antibodies have more direct effect on the bacteria themselves by causing paralysis, agglutination or disintegration.

The white cells exercise their protective functions both in the blood and in the extravascular tissues. By means of amœboid movement they are able to pass between the cells of the capillary walls and enter the surrounding tissues, a process termed diapedesis. This occurs on a particularly extensive scale in inflammatory conditions, when large reserves of white cells, borne to the affected part by an increased blood supply, are attracted out of the capillaries by a chemical substance formed by the injured tissues.

The number of white cells in circulation varies considerably according to the needs of the body. When necessary their production can be speeded up and large numbers of reserve cells pass into circulation from the liver, the spleen and the lymphoid organs. An acute infection is usually productive of a marked increase in the white cell count. This tends to rise also when the body's general resistance is lowered, in conditions conducive to infection such as fatigue and chilling, and during pregnancy. There are some slight variations also at different times of the day.

The ability of the blood to clot helps to prevent infection from entering the blood stream by sealing the ruptured vessel and blocking the entrance of dirt and bacteria.

THE TISSUE FLUID AND LYMPH

All the cells of the body are surrounded by a fluid from which they derive the materials for their metabolic processes, and into which their waste products are passed. The cells are very sensitive to the chemical composition and physical properties of their liquid environment, any alteration of which directly affects their ability to function efficiently. The blood not only provides the tissue fluid by filtration through the capillary walls, but maintains the constancy of its physical and chemical condition.

In composition the tissue fluid is related to, but not identical with, the plasma of the blood. Some of the constituents of the plasma, notably the proteins, do not pass easily through the capillary walls and are therefore present at a much lower concentration in the tissue fluid. All diffusible substances are at approximately the same concentration as in the blood. As certain materials are removed from the fluid by cellular activity their level falls slightly below that in the plasma; at the same time the concentration of waste products in the tissue fluid tends to rise, and these differences in concentration are responsible for the exchanges by diffusion between the blood and the tissue fluid. The tissue fluid contains a variable number of white blood corpuscles which have left the blood vessels by diapedesis.

Formation of the Tissue Fluid

The formation of tissue fluid depends on the blood pressure in the capillaries being higher than the fluid pressure in the tissues. Filtration is greater at the arterial end of the capillary, where the blood pressure is higher, than at the venous end. A rise in blood pressure causes a more copious flow from the capillaries, while a fall slows or even stops filtration. If the pressure of blood falls below that in the tissues, fluid will pass back into the blood.

Osmosis also influences the formation of the tissue fluid. Because of the normally higher osmotic pressure of the blood, due largely to the retention of proteins in the plasma, there is a tendency for water to pass back from the tissues into the blood, particularly at the venous end of the capillary. This exerts a check on excessive filtration into the tissues, as well as helping to regulate the concentrations of both the tissue fluid and the blood. Any tendency for the blood to become more concentrated results in a withdrawal of water from the tissues; while dilution of the blood or a rise in the tissue fluid concentration causes the passage of water in the opposite direction.

Drainage of Fluid from the Tissues

The continual filtration of fluid from the blood is normally balanced by its removal from the tissues. Some fluid is absorbed by the tissue cells, some may return to the blood stream by osmosis, while the remainder is gradually drained from the tissue spaces into the lymphatic vessels. The lymphatic vessels start as fine capillaries lying in close contact with the tissue cells. Like the blood capillaries, they are formed of a single layer of endothelial cells. The flow of tissue fluid into the lymph capillaries is encouraged by the comparatively high fluid pressure in the tissues. Similarly, the fluid in the serous cavities is controlled by the continuous filtration into the networks of lymph capillaries which lie in close connection with the linings of these cavities.

The flow of lymph throughout its course is assisted by the contraction of muscles and the movement of joints; back flow being prevented by the valves in the lymph vessels. The suction action produced by the negative pressure in the chest, especially during inspiration, and variations in intra-abdominal pressure are particularly valuable in promoting the flow in the thoracic duct (the largest lymph vessel) as it passes through the abdominal cavity and thorax to empty its contents into the veins at the base of the neck.

The lymph carries with it substances formed in the tissues including waste products. In the small intestine the lymph capillaries, known as lacteals, start in the villi, from which they collect the fat resulting from food digestion and absorption. This lymph, resembling milk, is known as chyle.

In its course from the tissues the lymph passes through various lymphatic glands. Here it comes into contact with lymphoid and reticulo-endothelial tissues. The reticulo-endothelial cells destroy by phagocytosis micro-organisms or injurious foreign bodies which may be present, and the lymphocytes are capable of neutralizing any toxins in the lymph stream. In addition the lymph carries away from the lymph glands some newly formed lymphocytes and a few monocytes, which it passes into the blood.

Cerebro-spinal Fluid

The tissue fluid of the central nervous system is known as the cerebro-spinal fluid. It bathes the tissue elements and is present in considerable quantities in the ventricles of the brain, the central canal of the spinal cord, and between the meninges covering the brain and spinal cord. It is formed by a process of combined secretion and filtration from the choroid plexuses: these are highly vascular tufts of tissue covered by cubical epithelium, which project into the ventricles. This fluid is practically free of cells and contains only traces of proteins.

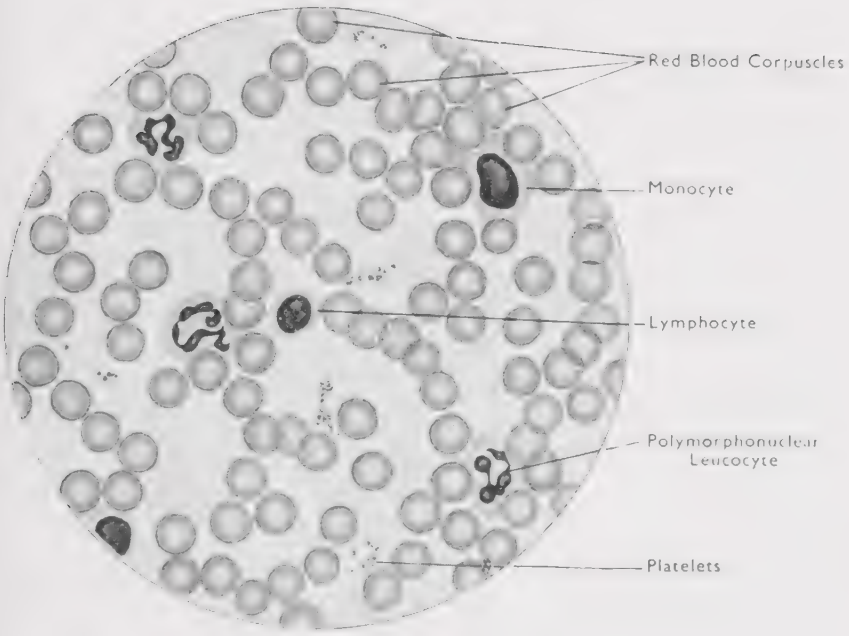
As well as carrying out the usual functions of tissue fluid, the cerebro-spinal fluid assists in regulating the intracranial blood pressure. In its position between the meninges it acts as a water cushion protecting the brain and spinal cord. It also receives the secretion of the pituitary gland.

The greater part of the cerebro-spinal fluid is returned to the venous sinuses in the cranial cavity. Some also passes through the lymph spaces round the cranial and spinal nerves and so enters the lymphatic vessels.

Fig. 38

BLOOD FILM. × **550.**

In preparing a blood film the plasma is evaporated so that only the corpuscles remain. The red corpuscles are the most numerous. They are small rounded discs without nuclei, although the centre of each being thinner than the rim sometimes looks like a nucleus. The nucleated structures are the white cells of various types. The polymorphonuclear leucocytes (neutrophil granulocytes) are present in large numbers and are easily recognized by their highly lobulated nuclei. Occasionally one or two other cells with lobulated nuclei, but with more coarsely granular cytoplasm, may be seen. These are the acidophil and basophil granulocytes (not shown in this drawing). They may be distinguished from each other and from the polymorphs by the staining of their granules. Next most numerous to the polymorphs are the lymphocytes. These are recognized by their darkly stained rounded nuclei. A few large lymphocytes can sometimes be found, also an occasional monocyte with its large and often indented nucleus and abundant cytoplasm. Some platelets may be seen in groups or scattered singly. They are very small, brightly shining bodies.


Red Blood Corpuscles
Monocyte
Lymphocyte
Polymorphonuclear Leucocyte
Platelets

CHAPTER VII

THE MUSCLE TISSUES

A description of the structure, arrangement and distribution of the three types of muscle tissue: together with an account of their functions and characteristic properties.

THE movements of the body and of its internal organs are dependent on the contractile properties of the muscle tissues. Three types of muscle tissue are found in the body: skeletal, visceral and cardiac muscle. Skeletal muscle is known also as striated or striped muscle, on account of the characteristic transverse striations shown by its fibres, and as voluntary muscle because it comes under the control of the higher motor centres of the brain. Visceral muscle is known as plain, smooth or unstriped muscle. It is innervated by the autonomic nervous system and is therefore also called involuntary muscle.

The muscle tissues consist of elongated cells called fibres. The contractile substance of the fibres is of specialized cytoplasm in the form of longitudinally arranged myofibrils; these are embedded in undifferentiated cytoplasm, called sarcoplasm. The more highly organized and well developed the fibrils, the greater the speed at which the fibre can contract.

The muscle fibres, with the occasional exception of visceral muscle, are incapable of cell division. When a tissue is damaged, regeneration takes place in those fibres which are only partially destroyed; the badly injured fibres degenerate and are replaced by connective tissue.

SKELETAL, VOLUNTARY OR STRIATED MUSCLE

This tissue forms the muscles which are attached to the skeleton, the muscles of facial expression, the extrinsic muscles of the eyes, and the muscles of the tongue, pharynx and larynx. Some is present, in addition to the visceral muscle, in certain organs such as the upper part of the œsophagus and the anal canal.

The Fibres

The units of skeletal muscle are multinucleate, cylindrical fibres. Each fibre resembles a fine thread with conical tapering ends.

The fibres vary considerably in size. An average length is from two to four centimetres, though fibres as short as 0·5 cm. and as long as 15 cms. have been isolated. In diameter they measure between 10μ and 100μ.*

Each fibre is surrounded by a continuous sheath, the sarcolemma, which is elastic and adapts to the changing shape of the fibre. The numerous oval nuclei lie directly beneath the sarcolemma.

The fibres show well marked transverse and faint longitudinal striations. The parallel arrangement of the myofibrils accounts for longitudinal striations. Each myofibril is divided throughout its length into segments which appear alternately light and dark, due to differences in the physical state and refractive properties of the protoplasm. Each dark segment forms the central portion of a single contractile unit, or sarcomere. The myofibrils are so arranged that their segments form dark and light discs extending through the whole thickness of the fibre, and accounting for the transverse striations. When a fibre

* μ = a micron, $\frac{1}{1000}$ th millimetre.

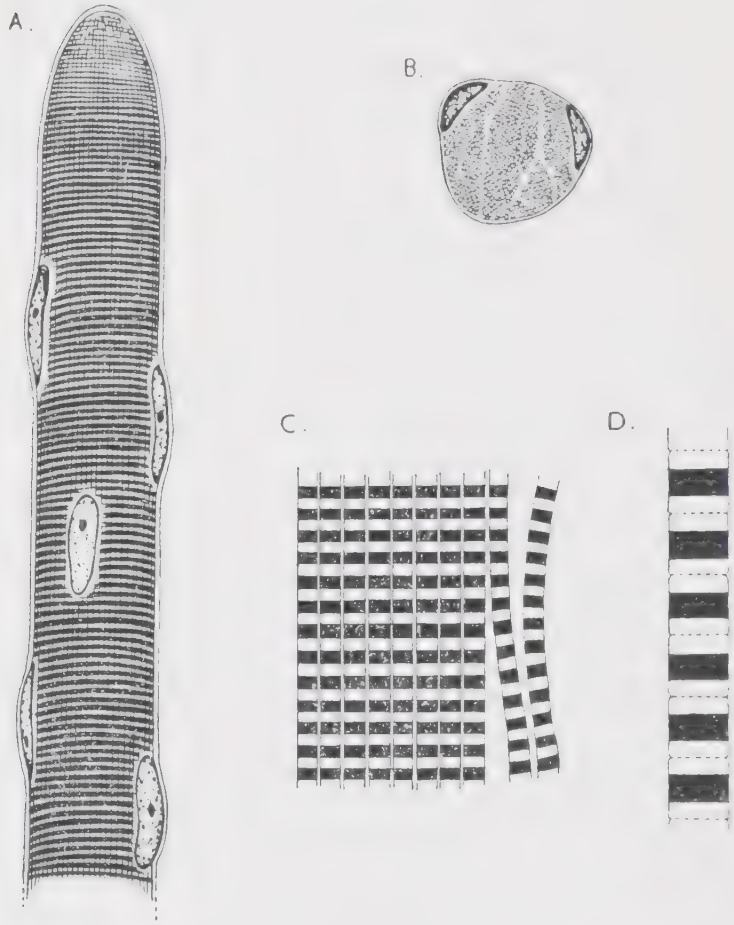


Fig. 39

DIAGRAMS SHOWING THE STRUCTURE OF A SKELETAL MUSCLE FIBRE

A The end of a fibre shown in length.
B Transverse section of a fibre.
C Parts of several myofibrils (further enlarged) showing how their arrangement is responsible for the transverse striations.
D Part of a myofibril (still further enlarged) showing its alternate dark and light segments and its divisions into contractile units (sarcomeres).

contracts there is an alteration in the relative thickness of these dark and light bands, probably due to changes in the molecular arrangement of the muscle protein.

Red and White Muscle

The red colour of muscle fibres is due both to its extensive blood supply and to the presence of a pigment, myohæmoglobin, in the sarcoplasm. Some fibres are more heavily pigmented than others, since they contain relatively larger amounts of sarcoplasm. Their myofibrils are therefore fewer and more widely separated. Muscles containing a preponderance of such fibres are called "red muscles." "White muscles" are composed mainly of fibres in which the fibrils are well developed and more numerous, and there is correspondingly very little sarcoplasm.

White muscles are swift and precise in contraction, but are easily fatigued. Red muscles respond more slowly and are capable of more prolonged contraction. Red muscles are responsible for the stability of joints and the maintenance of posture.

The Arrangement of Fibres in Muscles

The fibres lie parallel to each other in bundles. Between the fibres there is a small amount of areolar tissue, the endomysium. Surrounding each bundle is a more concentrated layer of connective tissue, the perimysium. The whole muscle, consisting of numerous fibre bundles, is further ensheathed by connective tissue, the epimysium. There is often a certain amount of adipose tissue between the bundles of muscle fibres.

The muscle is attached at either end to bone, cartilage or fascia by means of white fibrous tissue. A bundle of the white fibres passes to the end of each muscle fibre, penetrating or blending with the sarcolemma. Some white fibres continue into the intramuscular connective tissue.

Individual muscle fibres may span the full distance between the white fibrous attachments where these are sufficiently close to one another, but where these are more

Fig. 40

DIAGRAM SHOWING THE ATTACHMENT OF SKELETAL MUSCLE FIBRES TO THE PERIOSTEUM BY MEANS OF WHITE FIBROUS TISSUE

widely separated the fibres end within the muscle. The sarcolemma at the end of such a fibre blends with the intramuscular connective tissue, or with the end of a second fibre in the same line of pull. In this way the

traction of all the constituent fibres of a muscle is transmitted to the white fibrous tissue of its attached ends.

Blood Vessels and Lymphatics

Striated muscle has a very rich blood supply. The capillary vessels, supported by the endomysium, lie along the length of each fibre with frequently communicating branches. The main arteries and veins together with some lymphatic vessels lie between the fibre bundles. Red muscle is even more extensively supplied with blood vessels than is white muscle.

Nerve Supply

Each muscle is supplied by a nerve consisting of both motor and sensory fibres. Contraction of the muscle is stimulated by nervous impulses which reach it through its motor fibres. Each motor fibre arises from the central nervous system, its cell body lying in the anterior horn of the spinal cord or in the motor nucleus of one of the cranial nerves. Near to its termination the fibre divides into a number of branches. Each branch passes to a single muscle fibre where it ends as a collection of branching expansions within a raised nucleated mass of muscle protoplasm. This nerve ending, or motor end plate, lies directly beneath the sarcolemma. The external sheath of the motor fibre, the neurilemma, becomes continuous with the sarcolemma of the muscle fibre. One motor fibre may supply from 5 to 150 muscle fibres, which will contract together and are spoken of as a motor unit. The more delicate the action of the muscle the smaller are its motor units.

Impulses, set up either by passive stretching of a muscle or by its contraction, travel to the central nervous system along the afferent or sensory fibres. The receptor nerve endings of these fibres are present both in the muscle and its tendons. The receptors in the muscle

are contained in specialized end organs called muscle spindles. Each consists of a sheath of fibrous tissue enclosing a group of rudimentary muscle fibres which are embedded in more delicate connective tissue. Most of the nerve fibre endings wrap round the small muscle fibres in a spiral fashion (annulo-spiral endings); a few end in closely branching tufts (flower-spray endings). Within the spindle the nerve fibres have no sheaths. The muscles

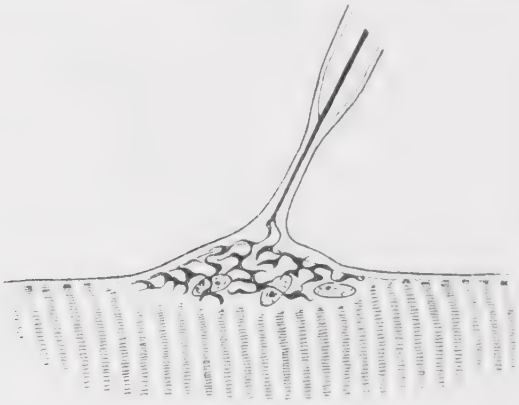


Fig. 41
DIAGRAM OF A MOTOR END PLATE
The muscle fibre is shown in part only.

responsible for the maintenance of body posture are especially well supplied with muscle spindles.

A tendon organ consists of the complex terminal branchings of several nerve fibres within a tendon bundle close to its junction with the muscle. A few nerve fibres terminate by branching freely in the intramuscular connective tissue.

The Properties of Skeletal Muscle and Characteristics of its Contraction

Under natural conditions a skeletal muscle will contract only when stimulated through its motor nerve: its

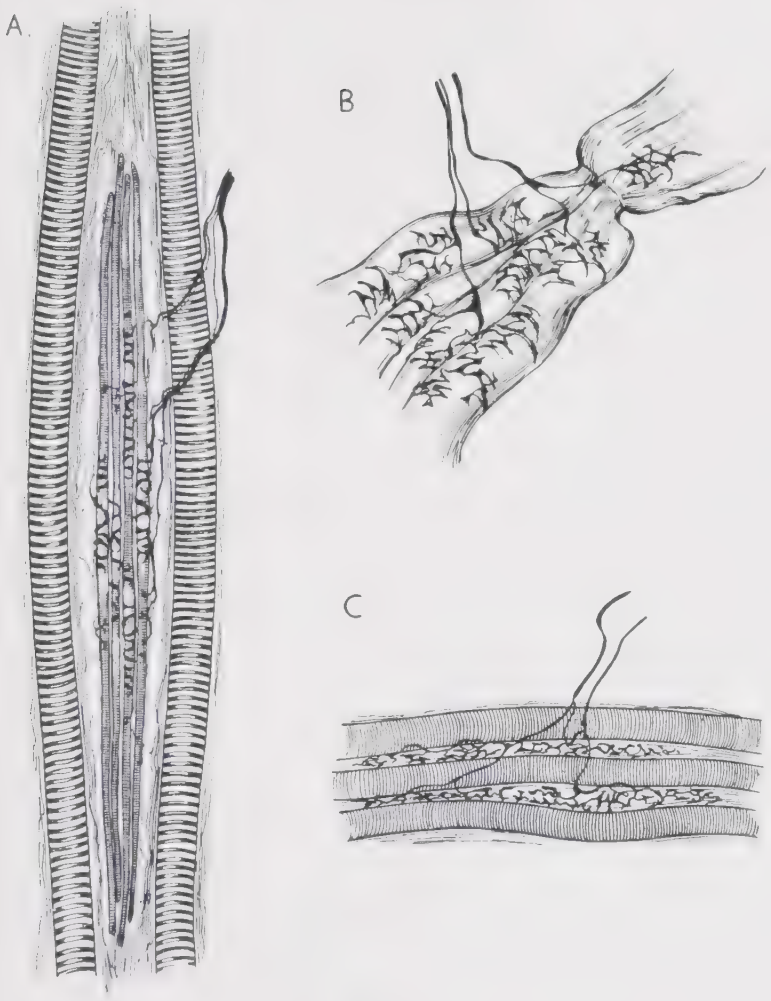


Fig. 42

DIAGRAM OF RECEPTOR NERVE ENDINGS IN SKELETAL MUSCLE

A Muscle spindle shown in length between two full-sized muscle fibres.
B Tendon organ.
C Nerve endings in intramuscular connective tissue.

contraction is said to be neurogenic. On stimulation the individual fibres obey the "all-or-none" law. This means that if a fibre contracts at all it does so to its full extent in the existing conditions. The strength of contraction of a muscle as a whole can, however, be graded according to the number of fibres in action simultaneously, and this depends on the strength of the nervous stimulus. A minimal response is produced by the contraction of a single motor unit. By increasing the strength of the stimulus more and more fibres are brought into action until the greatest possible number are all contracting. The smaller the motor units of a muscle the finer are the possible variations in the strength of its contraction.

A muscle responds to a single stimulus by a simple twitch. Immediately following the stimulus is a short latent period during which no visible change takes place. This period lasts for approximately $\frac{1}{500}$th second. This time allows for the impulses passing down the nerve to reach the motor end plates, for the excitatory state to be transmitted to the muscle and for the chemical charges setting free the energy for the contraction to take place in the muscle fibres. Then follows a short sharp contraction succeeded immediately by relaxation. The whole twitch lasts only $\frac{1}{10}$th second or less.

Under natural conditions single muscle twitches rarely, if ever, occur. The contractions resulting in normal movement and sustained states of contraction are dependent on streams of impulses impinging upon the muscle. When the discharge of impulses from the central nervous system is sufficiently rapid the individual contractions are completely fused, resulting in a strong, smooth and steady pull, known as tetanus. Should the discharge of impulses be slow enough to allow slight relaxation between each contraction the muscle fibres will contract in a vibratory manner. Usually, however, the discharge of impulses down the motor fibres is asynchronous, so that the motor units

do not contract simultaneously but one relaxes as another comes into action while the muscle as a whole appears to contract smoothly. The quicker the discharge of impulses the more complete the tetanus and the stronger the contraction; complete tetanus results in a pull about five times the strength of a single muscle twitch.

The response of a muscle is influenced by various factors. Preliminary stretching of a muscle causes both greater speed and strength of contraction due to the increased initial tension in the muscle. Similarly if a muscle is first "tensed" by contraction it is capable of producing quicker and stronger movement: (page 129).

The weight of the load which a muscle has to lift affects the contraction variously according to whether it is allowed to stretch the relaxed muscle first (free weighting), or is added after the contraction has started (after loading). In both cases an increase in load is, within limits, responsible for stronger contraction, but this effect is more marked in the free weighted muscle. While there is an optimum load beyond which any further increase causes a falling off in the strength of the contraction, the weight which can be added without diminishing the contraction is greater in the free weighted than in the after loaded muscle.

A rise in temperature, within limits, hastens both the contraction and relaxation of a muscle. Moderate heat causes also a slight increase in the strength of the contraction. Cooling has the opposite effect.

If a muscle is worked repeatedly without rest it eventually becomes fatigued. It responds less readily to stimulation, the latent period is lengthened, the contraction is slower and weaker, and the relaxation is slower and incomplete. These changes are progressive until no further response can be elicited. With rest and a good blood supply the neuro-muscular mechanism is capable of complete recovery. If, on the other hand, a muscle is

worked regularly but without undue fatigue its ability to work is increased. The muscle becomes thicker and firmer; this is due to an increase in the size of the individual fibres and not to an increase in their number. The muscle is then capable of stronger contraction and can be worked for longer periods without becoming fatigued.

Skeletal muscle is elastic and slightly extensible. These are purely physical properties and should not be confused with the shortening produced by contraction and the lengthening caused by relaxation. Both properties are of protective value. The amount of extensibility of skeletal muscle is difficult to estimate since passive stretching results in reflex contraction of the same muscle, and even when this is overcome the limit to extension is set more probably by the intramuscular connective tissue than by the muscle fibres themselves.

Group Action of Muscles

Even the simplest movement of the body is brought about by the integrated action of several groups of muscles which work together to ensure smoothness and accuracy. Those muscles whose contraction causes the movement are known as the prime movers. As they contract the opposing group of muscles, the antagonists, relax and lengthen, so allowing the movement to take place and at the same time controlling the speed and smoothness of the action. Any muscle which by its contraction or relaxation modifies the action of the prime movers is known as a synergist. These muscles may alter the direction of pull of the prime movers; or where the prime movers pass over more than one joint the synergists either steady the intermediate joint so that it takes no part in the movement, or act on it in such a way that the prime movers can work with the best mechanical advantage. A fourth group of muscles is known as the fixators. These muscles by their contraction steady the bones which give origin to

the other groups of muscles. In strong actions muscles throughout the body may be called upon to act as fixators. Any one muscle may, at different times, act as a prime mover, an antagonist, a synergist or a fixator. In the action of gripping, the flexors of the fingers and thumb (which are also flexors of the wrist) are the principal prime movers: the extensors of the fingers and the thumb are the antagonists: the extensors of the wrist work as synergists by opposing the secondary action of the prime movers, and by actually extending the wrist so that the flexion of the fingers is stronger and more complete. All muscles which are attached to the bones of the forearm, the arm and the shoulder girdle act as fixators.

Isotonic and Isometric Contraction

The term isotonic is used to describe contraction (or relaxation) which results in a change in the length of a muscle, but which does not markedly alter the intramuscular tension. When a movement is performed against the pull of gravity or some other external force, as when the arm is lifted sideways to shoulder level, the prime movers contract isotonically; that is they shorten as they produce the movement. On the other hand the antagonists are lengthening, relaxing isotonically. When the arm is again lowered to the side the muscles reverse their actions: but in this case gravity takes on the rôle of the prime movers, and the muscles which would draw the arm downwards are not responsible for causing the movement. They do, however, contract isotonically, adjusting to a shorter length as the movement proceeds and to some extent exerting a controlling pull on the moving part. Meanwhile the muscles which lifted the arm sideways now relax isotonically. According to whether this relaxation is sudden or gradual the arm will either drop as a dead weight or will be lowered slowly, the speed of the movement being controlled as the muscles "pay out."

When a muscle is prevented from shortening, its contraction will cause an increase in the tension between its attached ends. This is known as isometric contraction. It is used to tense the muscles, as in resisting some external force. A certain amount of isometric contraction generally precedes the production of a movement by isotonic contraction. Once sufficient tension is generated to overcome any resistance all further contraction will result in movement. Similarly the term isometric is applied to relaxation which results in a decrease in the intramuscular tension but not an increase in the length of the muscle.

A state of contraction may be sustained without alteration in either the length or the tension of the muscle. This form of contraction is sometimes called static muscle work, especially when the contraction is maintained voluntarily to hold some definite position. There is, however, a certain amount of contraction which is maintained reflexly in muscles, even at rest. This is known as muscle tone.

Muscle Tone

Under normal conditions some degree of tone is present in all skeletal muscles. It is maintained by the reflex contraction of some of the fibres which remain in action even when the muscle is apparently completely relaxed. The fibres contract in incomplete tetanus in response to a low frequency discharge of motor impulses from the central nervous system, but their contraction phases being "out of step" a steady tension is maintained. The extent of the tone depends partly on the number of fibres in action at one time and partly on the frequency of the motor impulse discharge. It is regulated primarily in response to nervous impulses received from the muscles themselves. Tone is weakest during sleep, but it is lost only when the motor nerve supply to the muscle is

interrupted, as when the nerve is severed, or by the action of certain drugs.

Tone prevents over-extension and tearing of the muscle and offers protection to underlying structures. The joints are stabilized and in many cases, such as the shoulder joint, their articular surfaces are actually kept in contact by the tension of the muscles surrounding them. If any of these muscles is subjected to stretching the tone is increased, preventing dislocation to the joint or strain to its tissues.

Muscle tone varies continually with the changing position of the body. It is weakest when the body is lying completely supported. In an upright position gravity stretches the muscles more strongly, causing an increase in tone sufficient to maintain the position. This postural tone is greatest in the extensor or antigravity muscles.

Muscle tone acts as a basis for swift and strong movement, since by it a certain tension is maintained in the muscles at all times. The greater the initial tone the less time and energy is spent before the movement can occur. The increased muscle tone associated with pain, fear, anger and excitement is of obvious advantage as a preparation for activity.

The heat production due to the continual slight contraction of the muscles helps to maintain the temperature of the body during periods of rest. Cold causes an increase in tone, which sometimes appears as shivering, with the result that more heat is generated. Warmth decreases the muscle tone.

Muscle tone helps to ensure an adequate blood supply to the muscles, and because of this prevents undue wasting when they are not in continual active use.

"Poor tone" is a term applied to muscles which are in a flabby condition. Such muscles are generally undersized, they fatigue quickly and tend to be slow and weak in contraction. "Excess tone" is an over-tension of the muscle. This may be due to over-development or to

excessive and prolonged nervous stimulation. Excess tone tends to produce an adaptive shortening of the intramuscular connective tissue, which then prevents full extension of the muscle and limits joint movement. The whole body musculature may show either poor or excess tone, or these conditions may affect individual muscle groups only.

VISCERAL, INVOLUNTARY OR PLAIN MUSCLE

Visceral muscle is found in the walls of the alimentary canal, in the respiratory tract, and throughout the urinary and genital tracts. It is present in the structure of the more solid organs such as the spleen, the lymph glands, the ovaries and various other glands. It is the main tissue in the middle coats of the smaller arteries, veins and lymphatics. It forms the intrinsic musculature of the eye. In the skin it forms the muscles attached to the hair follicles, and is present in the sweat glands, in the mammary glands, and the subcutaneous tissue of the scrotum.

The Fibres

Structurally visceral muscle is the simplest of the three muscle tissues. It consists of small spindle-shaped fibres, only a fraction of a millimetre in length. A single elongated nucleus lies within the cytoplasm in the thickest part of the fibre. The cytoplasm shows fine longitudinal striations but there are no transverse markings. The fibre is surrounded by a fine cell membrane but there is no true sarcolemma. In some positions the shapes of the fibres are modified. The ends are occasionally bifurcated. In the smaller blood vessels the cells are short and blunt. Contractile or myo-epithelial cells are found between the epithelium and the basement membrane of

certain glands. In the sweat glands such cells are strap-shaped and follow the coils of the tubule. In the salivary glands irregular cells with several tapering processes, called basket cells, lie external to the secreting epithelium. Myo-epithelial cells are found in the ducts of many other glands.

The Arrangement of the Fibres

The fibres of visceral muscle are usually arranged closely together in continuous sheets or masses, the tapering ends of some fibres fitting between the thicker

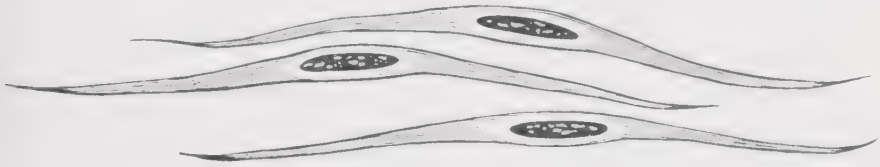


Fig. 43
DIAGRAM OF ISOLATED VISCERAL MUSCLE FIBRES

central portions of others. Between the fibres there is a minimum of retaining substance, probably consisting of very fine reticular and elastic fibres. In most hollow organs the tissue is in more than one layer, the direction of the fibres varying in the different layers. In certain places the circular muscle layer is thickened locally to form sphincters. In some positions visceral muscle fibres are found in connective tissue lying scattered or in small bundles.

Blood Vessels and Lymphatics

The blood supply of visceral muscle is poor in comparison with that of skeletal and cardiac muscle. Blood vessels and lymphatics run between the layers and masses of muscle, but there are no capillaries between the individual fibres.

Nerve Supply

Visceral muscle receives nerve fibres from both the sympathetic and parasympathetic divisions of the autonomic nervous system. The nerve fibres form plexuses in the surrounding connective tissue, from which fine branching fibres pass to end between or actually within the muscle cells. Receptor nerve endings are present in the intramuscular connective tissue.

Contraction and Properties of Visceral Muscle

Visceral muscle contracts rhythmically in waves which travel through the tissue, preceded and followed by zones of relaxation. Both the contraction and relaxation are very slow. This rhythmical contraction is responsible for the peristaltic waves which bring about the emptying of certain organs such as the urinary and gall bladders, and the propulsion along tubular structures like the intestine, the vas deferens and the ureter. In the alimentary canal the movements not only effect the passage of the food but mix it with the digestive juices and assist in its absorption.

The tone of visceral muscle is maintained by the partial contraction of all its fibres. Neither the tissue as a whole nor the individual fibres appear to obey the "all-or-none" law, as both are capable of greatly varying degrees of contraction. The tonic contraction of visceral muscle can be maintained over long periods of time without fatigue. Variations in tone account for alterations in the size and capacity of an organ, or in the calibre of a vessel. Where the regulation of size is the only function of the tissue, as in the blood vessels and in the sphincters, the muscle is arranged mainly in a circular manner, its contraction having a constricting effect and its relaxation allowing dilatation. Tonic variations are responsible also for the adaptive changes in the focussing apparatus of the eye, and for the erection of the hairs.

Unlike skeletal muscle the contraction of visceral muscle

is an inherent property of the muscle itself and can occur entirely independently of nervous stimulation. This is known as myogenic contraction. Both the rhythmic and tonic contractions are, however, influenced by the two sets of autonomic nerves, the one being a stimulating and the other an inhibiting effect. Myogenic contraction is affected directly by physical and chemical conditions. Stretching may have the effect of decreasing the tone to allow for increase in the capacity of an organ, as occurs in the bladder due to a gradual accumulation of urine. Alternatively the tone and rhythmic contractions of flaccid muscle may be increased in response to mechanical stimuli, as when food is taken into a resting stomach. Heat induces relaxation of the tissue, and cold stimulates its contraction. The contraction is affected also by certain hormones and drugs.

Visceral muscle is apparently highly extensible allowing for considerable distension of organs by their contents, though to what extent this is due to the passive stretching of the tissue or to a decrease in the muscle tone is not known. Under certain conditions the muscle fibres become hypertrophied. This is especially marked in the muscle of the uterus during pregnancy.

CARDIAC MUSCLE

Tissue Structure and Arrangement

Cardiac muscle is found exclusively in the structure of the heart. This tissue consists of long cylindrical fibres which lie parallel to each other. They frequently divide and rejoin and may also communicate by obliquely placed strands, called protoplasmic bridges. The fibres are incompletely divided into shorter cylindrical units by transversely placed intercalated discs. Each of these units contains one or sometimes two centrally placed nuclei. Such an arrangement of protoplasm in which

there are no distinct and separate cells is called a syncytium. The fibres are enclosed in very delicate sarcolemmal sheaths.

Cardiac muscle shows both longitudinal and transverse striations which are similar to, though less clearly marked than those in skeletal muscle. Undifferentiated sarcoplasm is particularly abundant round the nuclei and in the intercalated discs. The myofibrils are continuous throughout the whole tissue, passing through the discs and in the protoplasmic bridges.

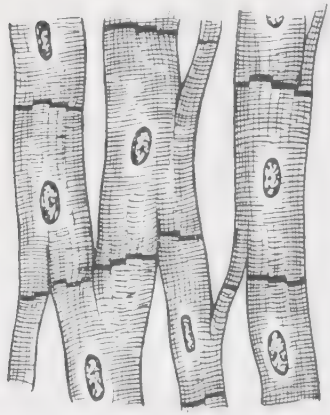


Fig. 44
DIAGRAM OF CARDIAC MUSCLE
Parts of three fibres are shown in length.

Cardiac muscle is concentrated into sheets and bundles, surrounded by areolar tissue, which penetrates also between the individual fibres. The sheets of muscle spread in a complex and coiling manner to form the walls of the chambers of the heart. The muscles of the auricles and of the ventricles are distinct from each other, being separated by the fibrous rings which surround the auriculo-ventricular openings, and are capable of independent contraction.

Atypical Cardiac Muscle

A system of atypical muscle fibres, known as Purkinje fibres, is present directly beneath the endocardium. These fibres are associated with two small nodes of concentrated neuro-muscular tissue in the wall on the right auricle. From the sino-auricular node, situated close to the opening of the superior vena cava, a fine network of Purkinje fibres spreads under the endocardium of both auricles, and ends by the blending of its finest branches with the typical

cardiac muscle of the auricle walls. The auriculo-ventricular node lies on the lower right side of the interauricular septum. It gives rise to a concentrated bundle of Purkinje fibres which pierces the fibrous tissue between the auricles and the ventricles and, dividing, passes down on either side of the interventricular septum to blend after extensive branching with the ventricle muscle. This

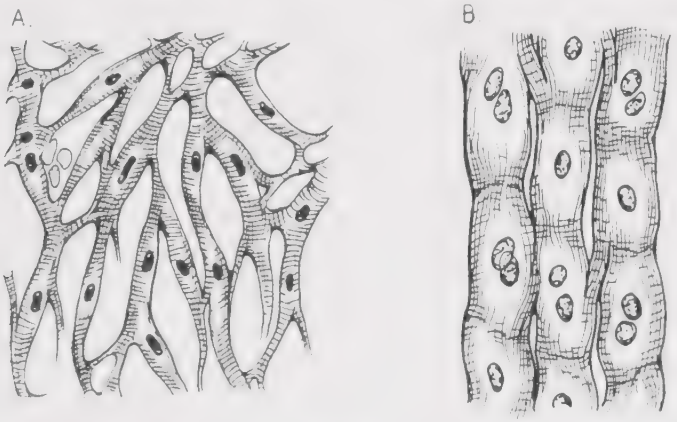


Fig. 45

DIAGRAM OF ATYPICAL CARDIAC MUSCLE

A Muscle fibres in the nodal tissue.
B Purkinje's fibres of the auriculo-ventricular bundle, shown in length.

auriculo-ventricular bundle forms the only muscular connection between the upper and lower chambers of the heart.

The Purkinje fibres differ in appearance from the rest of the cardiac muscle, and are more rudimentary in form. The fibres are larger and have fewer myofibrils, which are present only in the outer parts of the fibres; there are large amounts of sarcoplasm especially round the nuclei. In the nodes the muscle fibres are very much finer and more spindle-shaped. Here they form highly branching plexuses, supported in connective tissue and richly supplied with nerve fibres.

Blood Vessels and Lymphatics

A vast capillary network, derived from the coronary vessels, runs within the mass of cardiac muscle and surrounds the individual fibres. The main blood vessels and lymphatics lie in the connective tissue beneath the epicardial serous membrane.

Nerve Supply

Nerve fibres from the autonomic nervous system form plexuses in the connective tissue and from there pass to end in the muscle fibres, especially those of the nodes. Densely branching stretch receptor nerve endings are present in the endocardial connective tissue.

Cardiac Rhythm

Cardiac muscle contracts rhythmically. During each heart-beat the contraction spreads through the whole of the cardiac musculature propagated in a definite and orderly sequence by the Purkinje fibres, which for this reason are known as the conducting system of the heart.

Each wave of contraction begins in the sino-auricular node. This node is called also the pacemaker, since by the frequency of its contractions it sets the rate at which the whole heart beats. The contraction spreads rapidly through the network of Purkinje fibres to all parts of the auricle muscle, so that both auricles contract together. From the auriculo-ventricular node the contraction is transmitted down the auriculo-ventricular bundle and spreads to all parts of the ventricle muscle. By this means both ventricles go into simultaneous contraction as the auricles relax. Following ventricular contraction there is a period during which the whole of the heart muscle is relaxed before the next wave of contraction begins. The alternate phases of contraction and relaxation in either the auricles or the ventricles are called systole and diastole respectively.

During each heart-beat the blood is forced first by auricular systole into the ventricles, then by ventricular systole out into the arteries. The actual decrease in the size of the heart chambers is brought about by isotonic contraction of the cardiac muscle. This is always preceded by isometric contraction which serves to raise the pressure of the blood in the heart: it is especially effective at the beginning of the ventricular systole. As the heart muscle relaxes the pressure falls and the capacity of the chambers is increased to accommodate the blood flowing in from the veins.

Properties of Cardiac Muscle

The rhythmical contractions exhibited by cardiac muscle are the inherent property of the tissue itself, and occur independently of its nerve supply. This is shown by the cardiac muscle of the embryo, which commences to beat before its nerve supply is established.

Owing to the syncytial arrangement of the tissue and to the conducting system of Purkinje fibres the entire cardiac musculature is involved every time the heart beats. Each contraction is the fullest possible under whatever conditions exist at the time, so that the whole heart is said to obey the "all-or-none" law.

Cardiac muscle is extremely sensitive to the composition of the fluid which bathes its fibres. In this way the frequency of contraction waves from the pacemaker may be influenced by the composition of the blood. Sodium, calcium and potassium in correct proportions are all essential to the maintenance of cardiac contraction; an increased concentration of certain hormones such as adrenaline, and of metabolites particularly carbon dioxide, causes the heart to beat more quickly. A rise in the temperature of the blood has a similar effect. Nervous stimuli play an important part in controlling the rate of the heart-beat. Sympathetic impulses cause an

acceleration, while parasympathetic impulses have a slowing influence.

The more cardiac muscle is stretched, the more strongly will it contract. This means that the strength of the beat is largely dependent on the amount of blood entering the heart during diastole. The composition and temperature of the blood also have some effect on the strength of the contraction.

Cardiac muscle is moderately extensible, allowing of a certain amount of distension of the heart during diastole. Its elasticity helps to prevent any over-distension or injury to the fibres.

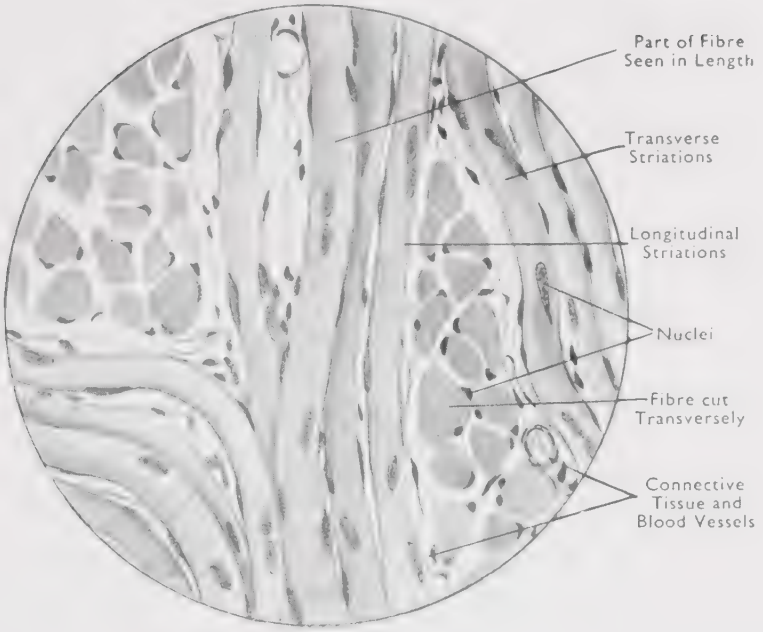


Fig. 46

SKELETAL MUSCLE. × **200.**

The drawing shows bundles of skeletal muscle fibres, some in longitudinal and others in transverse section. Only a short portion of the length of each fibre can be seen in the microscopic field, but it shows the unbranching nature of the fibre and its many nuclei. The transverse striations appear as fine dark lines across the fibres: they are easily seen under the microscope. The longitudinal striations are less well marked. The position of the nuclei on the outside of the contractile substance, directly beneath the sarcolemma, is best seen in the fibres cut transversely. These show also the diversity of size of the fibres. Their flattened sides are due to mutual compression, as the fibres are closely packed during life. The appearance of separation in the illustration is due to shrinkage in the preparation of the tissue.

Fig. 47

MOTOR NERVE ENDINGS IN SKELETAL MUSCLE.
× 160.

This is a teased preparation of skeletal muscle in which a special staining technique has been used to demonstrate the nerve fibres and their endings. In this drawing some of the branches of a motor nerve fibre are shown passing to a bundle of muscle fibres. As they near their termination the nerve fibres separate from each other and each passes to a different muscle fibre where it ends as a concentrated branching mass, the motor end plate. Where an end plate shows in profile it can be seen to cause a slight protrusion of the surface of the muscle fibre. For simplicity's sake all the fibres and motor end plates are drawn as if they were in focus simultaneously. In practice, since all lie on slightly different planes each requires a separate adjustment of the focussing apparatus to be seen distinctly. The nuclei of the muscle fibres and the sheaths of the nerve fibres are not demonstrated by this method of staining.

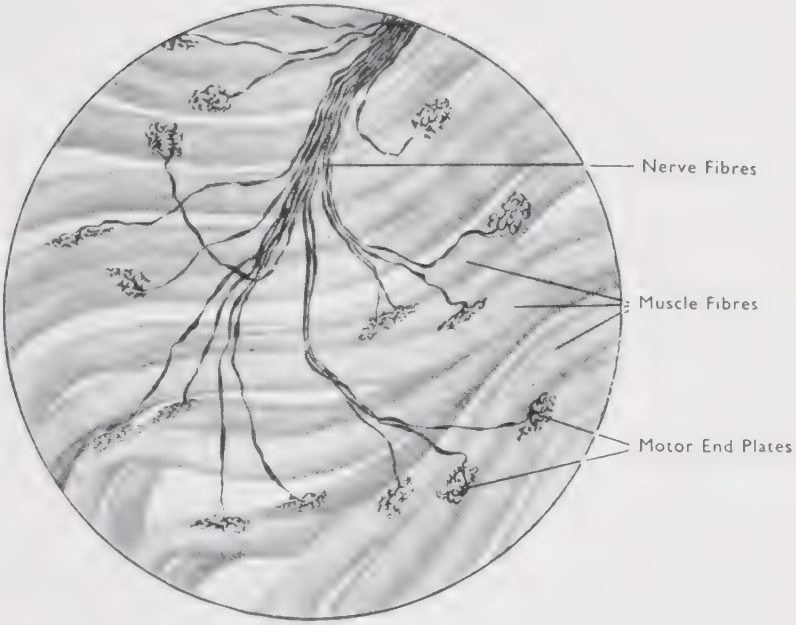

Nerve Fibres
Muscle Fibres
Motor End Plates

Fig. 48

VISCERAL MUSCLE IN LONGITUDINAL AND TRANSVERSE SECTION. INTESTINE. × 550.

This drawing shows a section through the junction of the circular and longitudinal muscle layers of the intestine. In this way the visceral muscle fibres are seen both in length and cut transversely. Owing to their closely packed arrangement it is difficult to pick out individual muscle fibres in their full length. The thicker central part of each fibre is comparatively easy to distinguish and is seen to contain a single elongated nucleus, but the tapering ends seem to disappear as they fit in between the other fibres. In transverse section the fibres are shown to be arranged in bundles, separated by strands of connective tissue. The apparent variation in the size of the fibres is due to the section having passed through the thicker central parts of some fibres and through the tapering ends of others. A nucleus is seen only where the section passes through the central portion of a fibre.

Fig. 49

CARDIAC MUSCLE. LONGITUDINAL SECTION. × 475.

In longitudinal section the fibres of cardiac muscle are seen lying parallel to each other, but the individual fibres are not always easy to distinguish because of their anastomosing arrangement. The protoplasmic "bridges" which connect adjacent fibres can be seen passing obliquely between them. The intercalated discs which divide the fibres into shorter lengths can be seen at intervals passing transversely across the fibres. They show either as dark lines or, where there is a certain amount of separation of the cytoplasm as in this preparation, as light bands. The oval nuclei of the fibres lie centrally in the fibre units. Other smaller nuclei lying between the fibres belong to the connective tissue. With careful focussing the longitudinal and transverse striations may generally be seen, giving the fibres a faintly checked appearance. These markings are fine and are not always clear.

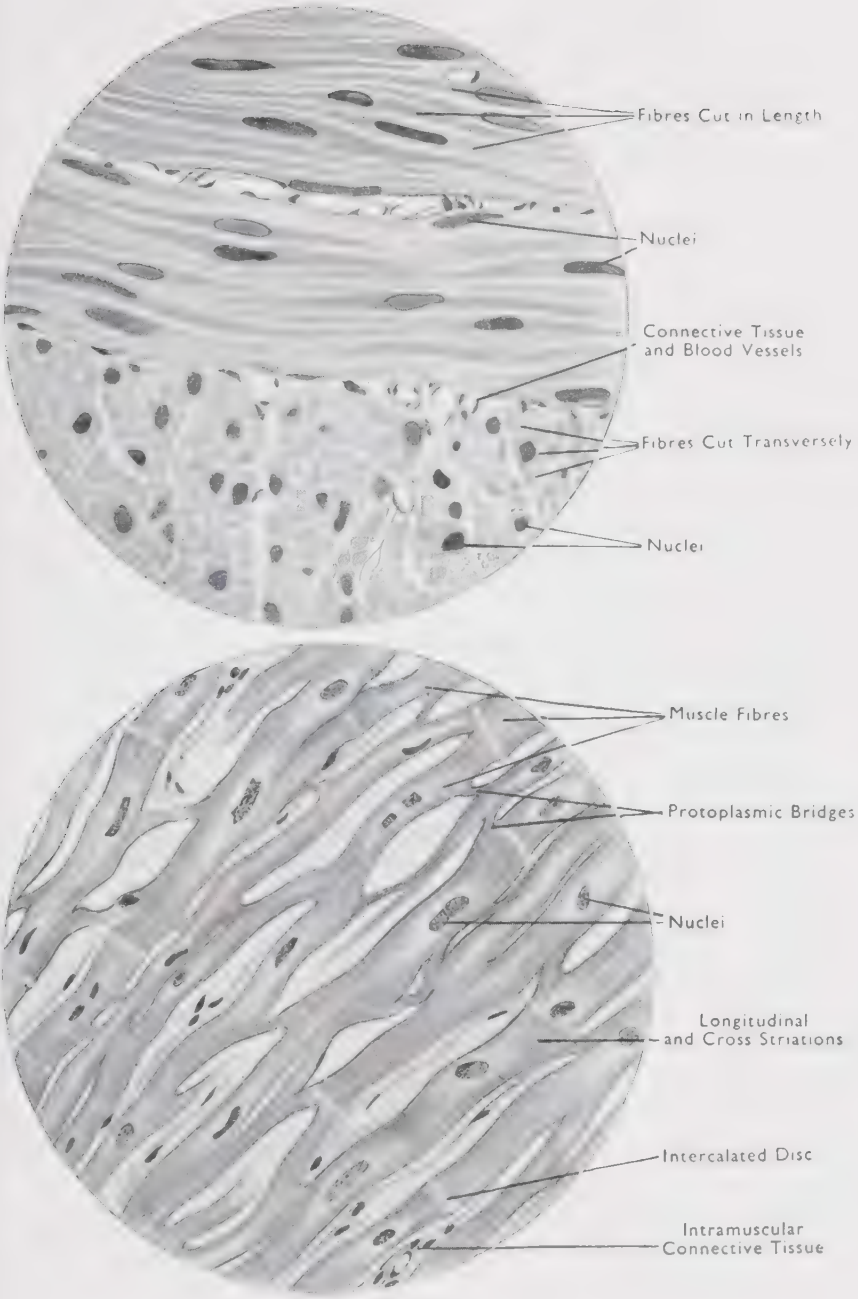
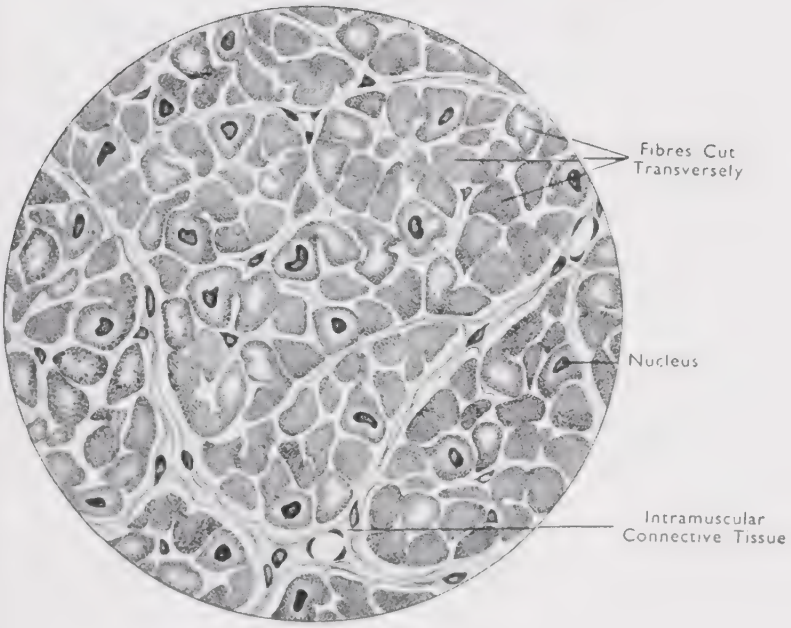

Fibres Cut in Length
Nuclei
Connective Tissue
and Blood Vessels
Fibres Cut Transversely
Nuclei
Muscle Fibres
Protoplasmic Bridges
Nuclei
Longitudinal
and Cross Striations
Intercalated Disc
Intramuscular
Connective Tissue

Fig. 50

CARDIAC MUSCLE. TRANSVERSE SECTION. × 300.

The muscle fibres are seen cut transversely, their flattened sides being due to mutual compression. Notice that in places two or three fibres appear to be joined together: this is where the section passes through the fibres as they are branching. The protoplasmic "bridges" appear as small sized fibres. In some fibres the nucleus can be seen embedded in undifferentiated sarcoplasm which appears lighter than the fibrillated periphery of the fibre. The light central area in other fibres is due to the section passing through this same sarcoplasm which extends in a cone both above and below the level of the nucleus. Notice the arrangement of the fibres into bundles ensheathed by connective tissue: fine connective tissue strands pass also between the individual fibres.


Fibres Cut
Transversely
Nucleus
Intramuscular
Connective Tissue

CHAPTER VIII

THE NERVOUS TISSUES

A summary of the general form and function of the nervous system, followed by a detailed account of the structure, arrangement and properties of the specialized conducting tissue, and of the neuroglia: also a description of the effects of injury to these tissues and of their regenerative processes.

TWO tissues are found exclusively in the structure of the nervous system: they are the nervous tissue proper, formed of specialized conducting cells, and an interstitial tissue called neuroglia. Nervous tissue is the most highly organized of the body tissues. Before the details of structure, arrangement and action of the individual cells can be appreciated, some knowledge of the general form and function of the nervous system as a whole is necessary.

THE FORM AND FUNCTIONS OF THE NERVOUS SYSTEM

The functions of the nervous system are to bring about, to control and to co-ordinate the reactions by which the body adapts itself to changes in its external environment. To fulfil these functions the nervous system is formed of afferent and efferent constituents and of nerve centres. The afferent constituents transmit impulses to the nerve centres from those parts of the body which are sensitive to external and internal changes (receptors); while the efferent constituents conduct impulses from the nerve centres to the tissues which will produce the response (effectors). The nerve centres are responsible for dispatching the efferent impulses to the appropriate effector

organs in accordance with the "information" they receive from the receptors.

The nervous system is, for descriptive purposes, divided into the central nervous system which comprises the brain and spinal cord, and the peripheral nervous system consisting principally of the nerves. The nerve centres are located within the central nervous system, and the nerves contain the afferent and efferent fibres linking the central nervous system with the receptor and effector organs.

The Central Nervous System

The substance of the brain and spinal cord shows, on section, parts which are pinkish-grey in colour and other parts which have an opaque white appearance. The grey matter represents the actual nerve centres, while the white matter is formed of nerve fibres passing to or from these centres.

In both the cerebrum and the cerebellum the grey matter forms a continuous and convoluted outer layer or cortex, which encloses the white matter. There are also isolated patches of grey matter in the depths of the white matter. In the other parts of the brain (mid brain, pons and medulla) the grey matter is arranged principally in irregular masses within the white matter. In the spinal cord the grey matter is centrally placed. Here it forms a column, roughly H-shaped in cross-section, which extends through the whole length of the cord, completely surrounded by white matter.

The substance of the brain is arranged around four irregular, communicating cavities known as the ventricles. The fourth ventricle is continuous with a canal which extends down the centre of the spinal cord. Both the ventricles and the spinal canal are filled with cerebro-spinal fluid.

The Peripheral Nervous System

The peripheral nerves, consisting of nerve fibres, extend from the brain and spinal cord. The twelve pairs of cranial

nerves pass to supply structures in the head, neck, thorax and abdomen. Some of these nerves contain afferent fibres only, but in others there are both afferent and efferent constituents.

The spinal nerves are distributed to nearly all parts of the body. Each nerve is attached to the spinal cord by two branches called the posterior and anterior roots. These blend together as the nerve emerges from the vertebral canal. The posterior root is composed of afferent fibres, while the anterior root contains efferent fibres only.

The nerves branch frequently as they extend further from the central nervous system and in places form complicated networks or plexuses. On the course of some of the nerves are nodular enlargements termed ganglia. Some of these, such as the posterior root ganglia, are associated with the afferent nerves. Others occur on the course of efferent nerves, but only on those which form the autonomic nervous system.

The Autonomic Nervous System

This system consists of all those efferent nerves and their associated ganglia which control involuntary muscle, cardiac muscle and glandular tissues. The system is divided into the sympathetic and parasympathetic systems. The sympathetic nerves arise from the thoracic and upper lumbar segments of the spinal cord in conjunction with the spinal nerves, from which they branch to pass to two chains of ganglia, one on either side of the vertebral column. From these, branches pass either to other ganglia in the thoracic and abdominal cavities, or to rejoin the spinal nerves. The parasympathetic nerves arise along with certain of the cranial and sacral nerves. They also are connected with small ganglia close to the structures they supply.

Practically all the effector tissues controlled by the

autonomic nervous system receive fibres from both the sympathetic and the parasympathetic divisions.

The two divisions, though working in opposition, are complementary to each other.

The Meninges and the Nervous Sheaths

The brain and spinal cord are surrounded by membranes of connective tissue called the meninges. The pia mater, which closely invests the nervous tissues, is composed of areolar tissue and contains numerous blood vessels. Highly vascular tufts of pia mater, covered by cubical epithelium, project into the ventricles of the brain as the choroid plexuses: from these the cerebro-spinal fluid is derived. The outermost meningeal layer, the dura mater, is of strong fibrous tissue. Between these two membranes is the delicate arachnoid mater, separated from the dura mater by the slit-like sub-dural space, and from the pia mater by the subarachnoid space. A network of fine connective tissue fibres stretches across the subarachnoid space connecting the arachnoid to the pia mater. The interstices of the arachnoid mater, the sub-dural and subarachnoid spaces are all filled with cerebro-spinal fluid.

The peripheral nerves and ganglia are ensheathed by connective tissue which is continuous with the meninges. A very small amount of fine areolar tissue, called the endoneurium, is present between the individual fibres. In the larger nerves the fibres are arranged in bundles. Each bundle is surrounded by a lamellated sheath of fibrous tissue, known as the perineurium. The bundles are held together and the whole nerve is invested by the epineurium of dense areolar tissue. The epineurium contains fat, small blood vessels and some nerve fibres which supply structures in the sheath itself. The epineurium is absent from small nerve branches which consist of a single bundle only. The perineurium invests

the smallest branches and becomes continuous with the connective tissue of the organs supplied or with the capsules of the nerve endings.

NERVOUS TISSUE PROPER

Neurones

The specialized conducting cells of nervous tissue are called neurones. Each neurone consists of a cell body, containing a single nucleus, and of cell processes formed by the elongation of the cytoplasm into thin filaments. The cell processes are of two types. Short processes which branch close to their junction with the cell body are known as dendrons. A main conducting filament is called an axon or nerve fibre process.* Most neurones have one axon only, but some have two axons and no dendrons. The axon is generally considerably longer than the dendrons of the same cell, and in some cases may measure as much as three or four feet. Throughout its length the axon is of almost constant thickness and gives off only small collateral branches. It terminates by ramifying freely.

The cell bodies of most neurones are situated in the central nervous system, where, surrounded by their dendrons, they form the principal constituents of the grey matter. Smaller groups of cell bodies are present in the peripheral nervous system constituting the ganglia. In most cases the axons pass from their cell bodies in the grey matter, or in the ganglia, to run in the white matter or in the peripheral nerves.

The neurones may be classified according to the shape of their cell bodies, which is determined by the number and arrangement of their cell processes.

* Many authorities distinguish between the processes of neurones on functional grounds alone. All processes by which impulses pass towards the cell body they call dendrons, while those which conduct away from the cell body are termed axons. In this chapter the author adheres to the structural classification of cell processes implied by the original meanings of the words dendron and axon.

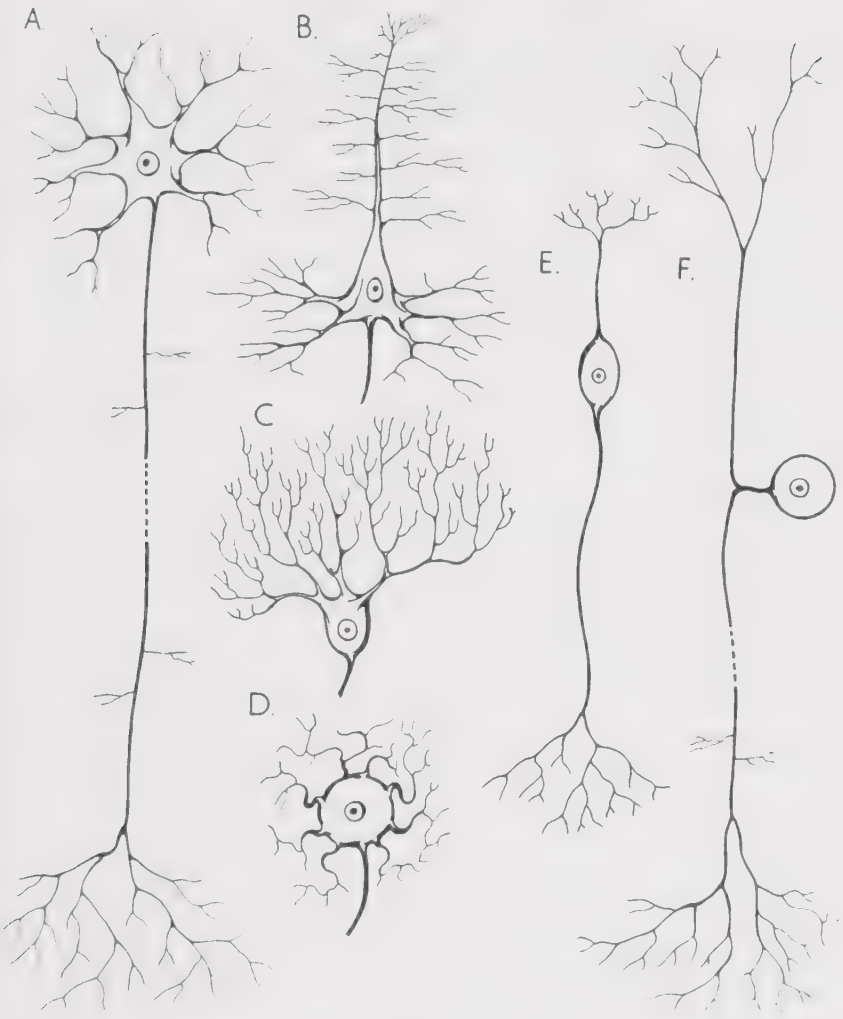


Fig. 51

DIAGRAM OF THE VARIOUS TYPES OF NEURONES

A Typical multipolar neurone with stellate cell body (motor neurone).
B Pyramidal cell body from cerebral cortex.
C Purkinje cell from cerebellar cortex.
D Ganglion cell from sympathetic ganglion.
E Bipolar neurone.
F Unipolar (pseudo-unipolar) neurone.

Multipolar Neurones

The majority of neurones have multipolar cell bodies. The cell body gives rise to numerous processes of which one only is an axon. While practically all the cell bodies which lie in the central nervous system are of this class, they vary in shape in different parts of the grey matter according to the arrangement of the cell processes. Typical examples are the stellate cells of the anterior horn of the spinal cord, the pyramidal cells of the cerebral cortex and the flask-shaped cells of the cerebellar cortex.

Bipolar Neurones

These neurones have two processes which arise from opposite poles of the cell body. Each process extends for some distance before branching. That process by which impulses pass towards the cell body, and which incidentally is usually the shorter of the two, is classed as the dendron. All bipolar neurones are afferent in function. There are comparatively few in the fully developed nervous system. They are present in the retina of the eye, the olfactory membrane of the nose, and in both the cochlea and vestibular branches of the auditory (VIIIth cranial) nerve; the cell bodies lying in the ganglia associated with this nerve.

Unipolar Neurones

Some neurones appear to have one process only which, a short distance from the cell body, divides into two branches. The branches extend in opposite directions, and each is, structurally, a typical axon or nerve fibre process. These cell bodies lie in the posterior root ganglia of the spinal nerves, or in the corresponding ganglia of some of the cranial nerves. One process runs into the peripheral nerves, the other passes into the central nervous system. These neurones are all afferent in function.

At an early stage in their development these neurones are bipolar, but their two processes gradually grow towards each other until they are so blended that they appear to leave the cell body as a single strand. For this reason they are sometimes called "pseudo-unipolar."

All developing neurones pass through a stage when they have only one process, but in the mature nervous system there are few true unipolar cells. These are found in the central nervous system, and are considered to be rudimentary.

The Cell Body

The cell body is the life centre of the nerve cell. It controls all the nutritive and excretory functions, but has no influence over the actual conduction of the impulses.

The cell body contains most of the constituents of a typical cell. The nucleus is large and centrally placed, and shows one or two clearly marked nucleoli. The surrounding cytoplasm contains numerous granules which, though not visible in the living cell, become precipitated after its death into irregular masses, readily stainable with certain dyes. These Nissl's granules are considered to be either food stores or substances related to the cell's nutritional processes. They vary in amount with the physiological activity of the cell, and disappear gradually from degenerating and fatigued cells. Nissl's granules are absent from that part of the cell body which gives rise to the axon. In certain preparations the cytoplasm shows a network of very fine threads termed neurofibrils which extend down into the cell processes. These are not visible in the living cell but they are thought to be present during life. Some cell bodies contain yellow or black pigment granules, with the result that the grey matter in which these cell bodies lie is similarly tinted. There is no centrosome in a nerve cell. This is probably related to the fact that neurones are incapable of cell division.

The Nerve Fibres

The axons of most neurones pass from their cell bodies in the grey matter or in the ganglia to run in the white matter of the central nervous system or in the peripheral nerves. There are, however, some neurones which lie entirely in the grey matter of the central nervous system. In these the axon is often so short and branches so close to the cell body that it is difficult to distinguish it from the dendrons. All axons around which a distinct fatty sheath can be demonstrated are termed medullated fibres. Others which have, apparently, no fatty sheath are called non-medullated fibres.

Medullated Nerve Fibres

Medullated fibres are the main constituents of the white matter and are present in large numbers in the peripheral nerves. The axon is surrounded by a white fatty material called myelin. This constitutes the medullary sheath, and is responsible for the white coloration when medullated fibres are massed together. In the peripheral nerve fibres the medullary sheath is interrupted at regular intervals for a fraction of a millimetre. These points of interruption are known as the nodes of Ranvier, and the portion between two nodes is called an internode. Branching of the axon occurs only at the nodes. There are no interruptions in the medullary sheaths of the fibres of the central nervous system and of the optic nerve. The medullary sheath commences a short distance from the cell body, and ends at the point where the terminal branching of the axon begins, or after ensheathing the larger of these branches. The function of the medullary sheath is not fully understood. It probably acts as an insulating layer around the axon, and may even assist in the conduction of impulses.

In the peripheral nerves the medullary sheath is in turn surrounded by a very fine tubular membrane known

as the neurilemma. This is formed of extremely flattened cells of neuroglial origin. A single neurilemma cell invests each internode, its nucleus causing a slight depression in the medullary sheath. At their edges adjacent neurilemma cells are united by a very small amount of intercellular substance. In this way a continuous membrane is formed which stretches across the nodes of Ranvier and invests the fibre throughout its full course. In many cases the neurilemma is continued around the terminal branches of

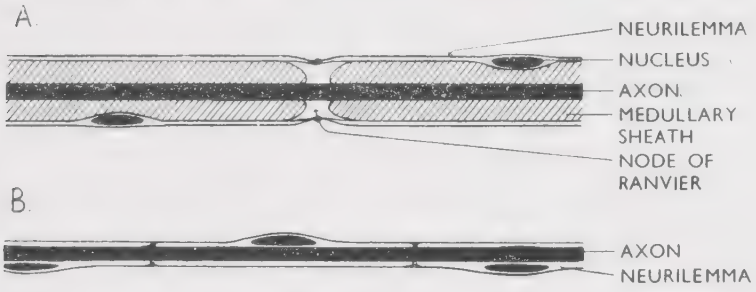


Fig. 52

DIAGRAM TO SHOW THE STRUCTURE OF NERVE FIBRES

A Portion of a medullated fibre.
B Portion of a non-medullated fibre.

the axon after they have lost their medullary sheaths. The neurilemma is fairly tough and often remains intact when the axon and the medullary sheath are ruptured. Its presence is essential to the regeneration of the nerve fibre after injury. In the central nervous system the medullated fibres have no neurilemma, and no regeneration can occur in these fibres.

Medullated fibres vary considerably in size. The largest, measuring from 20μ to 30μ in diameter, are those supplying the skin and the skeletal muscles. The smallest fibres are between 2μ and 4μ in diameter. These fibres pass from the central nervous system to the autonomic ganglia. The smaller the fibre the shorter is the distance between the nodes of Ranvier.

Non-medullated Fibres

A non-medullated fibre has no medullary sheath, but it is possible that the surface of the axon is covered by a fatty film too fine to be demonstrated by staining. In the peripheral nervous system non-medullated fibres arise from cell bodies in the autonomic ganglia and pass to supply effector tissues. These fibres are invested by neurilemmal sheaths. They are slightly finer than the smallest of the medullated fibres. Nerve branches consisting of non-medullated fibres only are grey in colour as distinct from the white nerves which contain a large proportion of medullated fibres. The axons of neurones which lie entirely in the grey matter of the central nervous system have neither neurilemmal nor medullary sheaths.

The Functional Connection between Neurones

The neurones are linked together into conducting chains or nerve pathways. These pathways allow impulses

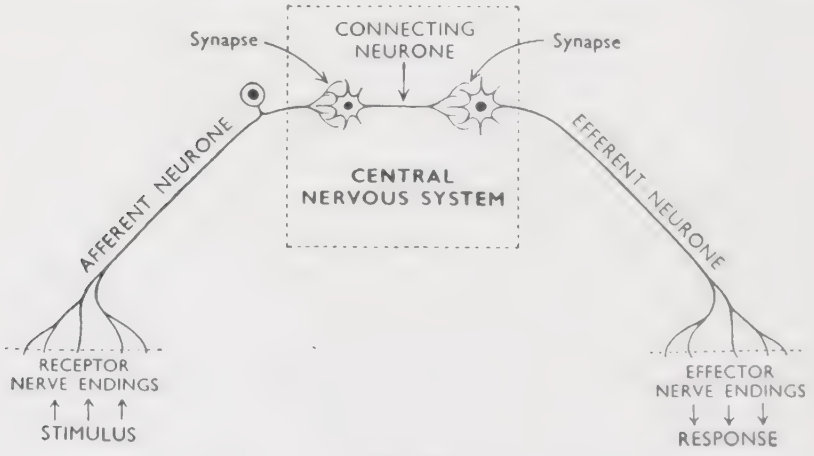


Fig. 53

DIAGRAM OF A SIMPLE NERVE PATHWAY

to travel without interruption from the point of stimulation to the tissues which will effect the response. At the

beginning of such a pathway is an afferent neurone which transmits impulses from the receptor nerve ending to the central nervous system. The final neurone of the pathway is efferent. It conducts impulses from the central nervous system to the reacting tissue, where it terminates as effector nerve endings. Linking the afferent and efferent neurones are internuncial or connecting neurones, which lie within the central nervous system. The length and complexity of the pathways vary according to the number of internuncial neurones.

Fig. 54

SYNAPSES FORMED BETWEEN TERMINAL BRANCHES OF A NERVE FIBRE AND A NERVE CELL AND ITS DENDRONS

Although each neurone of the pathway is structurally independent, impulses can pass from one neurone to another. The junction between two neurones is called a synapse. A synapse is formed by the terminal branches of an axon interlacing with the dendrons of another neurone, or by surrounding its cell body in a basket-like network. Where the terminal branches come into contact with the cell body or with the dendrons they may end in button-like expansions.

Within the central nervous system the synaptic connections between neurones are very extensive. For instance, the terminal branches of an afferent neurone may form synapses with a hundred or more internuncial neurones. In this way impulses entering the central nervous system have the possibility of spreading into many different pathways. On the other hand the axons of many neurones converge to form synapses with the dendrons of

a single efferent neurone, which acts as the final neurone common to many pathways.

Throughout life impulses are continually streaming from receptors in all parts of the body to the nerve centres in the central nervous system. These impulses in turn set up, inhibit, accelerate or decrease the impulses passing from the nerve centres to the effector organs. Even when the body is apparently inactive efferent impulses are responsible for maintaining, among other things, the tone of the voluntary muscles, the size of blood vessels, the flow

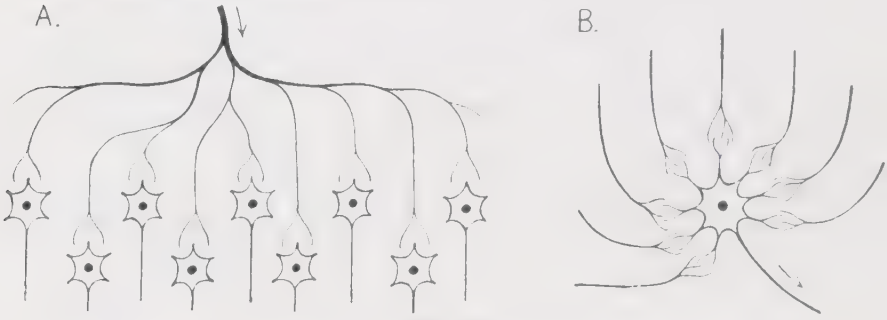


Fig. 55

DIAGRAM OF SYNAPTIC CONNECTIONS BETWEEN NEURONES

A Terminal branches of one neurone forming synapses with many other neurones.
B Terminal branches of many neurones forming synapses with a single neurone.

of secretions, the rhythm of breathing: all in accordance with the impulses received from the receptor nerve endings. Any change in the body's external or internal environment will result in reactions adjusting the body to the new conditions. Some of these reactions are initiated and controlled consciously. In these cases the efferent impulses originate from the higher (conscious) motor centres of the brain and are regulated in response to afferent impulses which, passing to the sensory cortex of the cerebrum, are appreciated as sensations. On the other hand numerous reactions occur without any conscious control, and often without any awareness that an adjustment has been made. This means that the nerve centres

involved do not function consciously. Such reactions are termed reflexes. Examples of reflexes include the constriction of the cutaneous blood vessels in response to cooling of the skin; the increased secretion of saliva in response to the taste, sight or smell of food; the constriction of the pupils of the eyes in a bright light, and the contraction of a muscle as a protective measure when it, or its tendon, is stretched.

THE CONDUCTION OF IMPULSES ALONG A NERVE PATHWAY

Nerve impulses are set up when a neurone is stimulated. Mechanical stimuli such as pressure and stretching, chemical, thermal and electrical stimuli are all effective. Stimulation usually occurs at the receptor nerve endings, which are the most sensitive parts of the nerve pathways. Each type of receptor endings responds to one form of stimulation only. As all the receptor endings of a single afferent fibre are of the same type these fibres possess specific irritability. When a fibre is stimulated at any point on its course, the result is the same as if the receptor endings had been affected. For example, by rubbing the eyes it is possible to stimulate the nerve fibres of the optic nerve and as a result sensations of light are experienced.

The least strength of stimulus which is effective is called the threshold or minimal stimulus. Some nerve endings have a lower stimulation threshold and are therefore more irritable than others.

After its initiation an impulse is self-propagating. An impulse may be described as a localized point of excitation which travels at high speed along a nerve fibre from the site of stimulation. Its passage is marked by chemical and physical changes, and by the discharge of electrical currents from the surface of the fibre. There is, however, no visible evidence of its passage.

Each impulse is immediately followed by recovery changes. During the time these changes are taking place, a period which lasts at any one point on the fibre from 0·001 to 0·005 second, no further impulses can be conducted and the fibre is said to be refractory.

Impulses continue to stream along the fibre as long as the stimulus is effective, and the proximity of each succeeding impulse is proportionate to the strength of the stimulus. There is no variation in the strength of the individual impulses since the neurones, obeying the "all-or-none" law, conduct to their full extent or not at all.

The speed at which impulses travel along any one fibre is constant, and is unaffected by the strength of the stimulus. The speed of conduction in the different fibres is proportionate to their diameters. It is greatest in the large medullated fibres supplying the skeletal muscles and the skin, and is slowest in the non-medullated fibres of the autonomic nervous system.

An impulse on reaching a synapse passes in one direction only, from the terminal branches of the axon to the dendrons of the second neurone. This is known as the law of forward direction.

Although impulses are said to cross a synapse it is more probable that they cause changes there which stimulate the next neurone. This theory is borne out by the fact that impulses are delayed slightly at the synapses. The stimulation of the second neurone is probably due to chemical substances produced at the synapse. No stimulation occurs until a certain minimal concentration is reached. This threshold is more quickly attained when the impulses impinging on a synapse are frequent and are continued for some time. In this way impulses set up by a strong original stimulus are more readily propagated across the synapses than those arising from weak and comparatively unimportant stimuli.

The threshold level, and therefore the resistance offered

by the synapses to the propagation of impulses, is variable. The importance of this is obvious if one considers the multiplicity of synaptic connections within the central nervous system. If all synapses offered equal resistance, impulses set up by a single stimulus would pass indiscriminately to all reacting tissues and no effective response would result. As it is, the course of an impulse is determined by the lower resistance of some synapses and the higher resistance of others. Many low resistance synapses are present at birth. These occur in the nerve pathways subserving the inborn reflexes. The resistance of synapses can be lowered by continual use. In this way "well worn" pathways are established for all the commoner reactions of everyday life.

On their arrival at the effector nerve endings the impulses elicit a response, the nature of which is determined by the physiological properties of the effector tissue. The actual stimulation is probably caused by chemical substances produced in the tissues at the effector nerve endings. In tissues which are supplied with one type of effector fibre only, such as skeletal muscle, the impulses stimulate activity which ceases as soon as the impulses stop. Where there are two sets of efferent fibres, as in cardiac muscle, two distinct chemical substances are formed, one at each effector ending. The one stimulates and the other inhibits the activity of the tissue.

NERVE ENDINGS

Receptor Nerve Endings

Receptor nerve endings are present in all parts of the body outside the central nervous system. They may be classified as exteroceptors or enteroceptors. The former are affected by external stimuli. The latter respond to changes within the body itself. All receptor endings which subserve muscle and joint sense are collectively termed

proprioceptors, and receptor endings in organs and vessels are referred to as viscero ceptors. The epithet "sensory" is often applied to receptor nerve endings and their afferent fibres; but this term is better limited to those nerve endings and fibres whose stimulation results in conscious sensation.

The terminal branches of some afferent fibres end freely, without any enclosing sheaths; others are encapsulated in connective tissue corpuscles.

Free Nerve Endings

The distal branches of an afferent nerve fibre, having lost their surrounding sheaths, ramify freely among the cells or fibrous elements of the tissue in which they lie. They may show bead-like enlargements at intervals, or have terminal varicosities or expansions. In some cases the terminal branching is so concentrated that the nerve ending appears as a spherical or spindle-shaped knot.

Free nerve endings subserving the sense of touch are present in the deep layers of the epidermis, especially in the tissue of the hair follicles. The endings pass into the epithelium from plexuses in the dermis. Finely beaded "pain" nerve endings are present in the epithelial and connective tissues in most parts of the body. Other free endings which act as stretch receptors are found in the connective tissue of most organs and blood vessels, in aponeuroses and tendons, and in intramuscular connective tissue: (page 122). Free nerve endings are present between the cells of sensory epithelia.

Encapsulated Nerve Endings

The nerve fibre ends by branching within a capsule of fibrous tissue so forming a corpuscle which is spherical or ellipsoidal in shape. These corpuscles lie in the connective tissues. They include the Pacinian corpuscles, which are found in the superficial fascia beneath the skin,

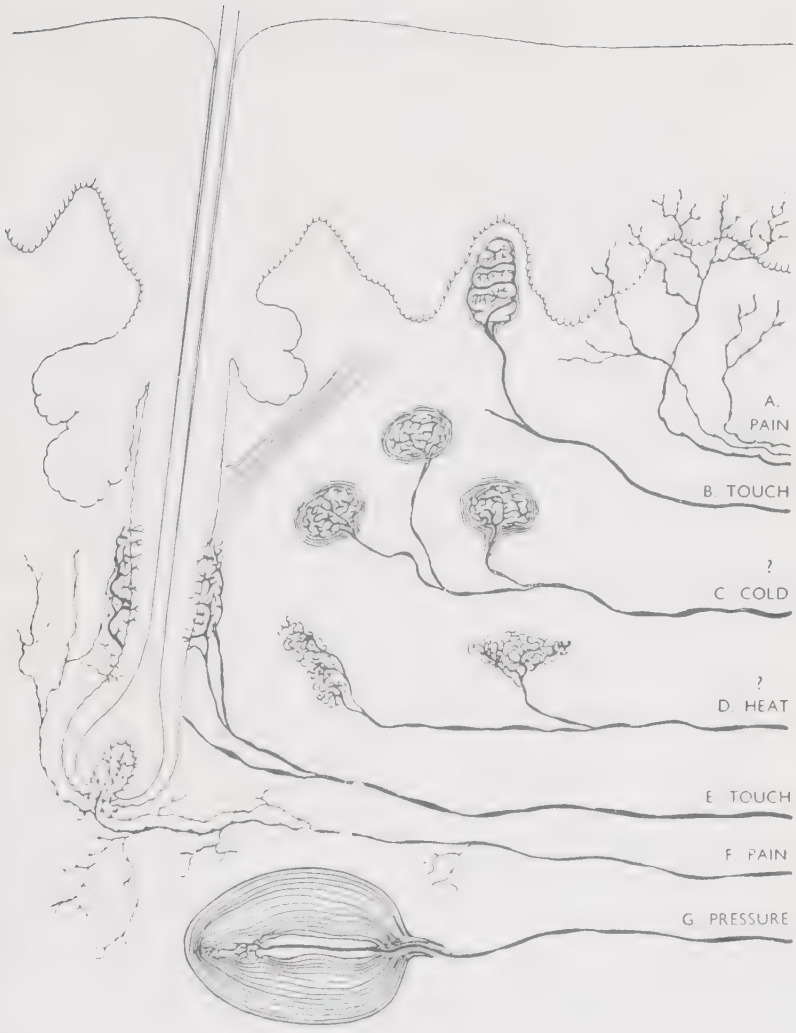


Fig. 56

DIAGRAM OF THE SENSORY NERVE ENDINGS IN THE SKIN

A Free branching nerve endings in upper dermis and lower layers of epidermis. (Pain.)
B Meissner's corpuscle in dermal papilla. (Touch.)
C End bulbs of Krause. (Cold.)
D End organs of Ruffini. (Heat.)
E Free branching nerve plexus round hair follicle. (Touch.)
F Free branching nerve endings in lower dermis and papilla of hair. (Pain.)
G Pacinian corpuscle. (Pressure.)

between tendons and muscles, in the fibrous tissue of the periosteum and of joint capsules, in the outer coat of the larger blood vessels, and in the peritoneum and the mesentery. Smaller spherical end bulbs also are found in similar positions, especially in the neighbourhood of joints. Both these corpuscles are stimulated by deep pressure. Meissner's touch corpuscles, stimulated by superficial pressure, are situated directly beneath the epidermis, in the dermal papillæ. They are numerous where the hairs are few or absent. Other corpuscles which are thought to respond to warmth and coolness respectively are the end bulbs of Krause and the end organs of Ruffini. They are situated chiefly in the dermis and the superficial fascia. The organs of Ruffini are often classed as free nerve endings as their capsules are exceedingly thin or may be absent. In skeletal muscle some nerve endings are encapsulated in special structures called muscle spindles: (page 127).

Effector Nerve Endings

Efferent fibres terminate in the muscles and glands as effector nerve endings. In skeletal muscle the terminal branches penetrate the sarcolemmæ of the muscle fibres and form motor end plates: (page 121). In visceral and cardiac muscle the efferent fibres form plexuses from which the terminal branches pass between, and often into, the muscle fibres. In some cases the nerve fibres have small terminal varicosities or branching expansions. In glands the nerve fibres form plexuses outside the epithelium. The terminal branches penetrate the basement membrane to end between the secreting cells.

The efferent fibres and their endings may be classified according to the response they elicit. Thus, motor fibres stimulate the contraction of muscle tissue: the fibres supplying the blood vessels are called vasomotor fibres, and are subdivided into vasoconstrictors and vasodilators:

the acceleratory and inhibitory fibres which supply cardiac muscle are named according to their effect on the heart rate: secretory fibres stimulate the activity of gland cells.

NEUROGLIA

The neurones are supported and to some extent invested by an interstitial tissue called neuroglia. Typical neuroglia cells have numerous processes extending from the cell body which contains a single nucleus. In some cells the processes branch elaborately, while in others they are long and thread-like and rarely branch.

Neuroglia is found principally in the central nervous system, both in the grey and in the white matter, supporting the cell bodies and their nerve fibres. The neuroglial cells around the cell bodies are often called satellite cells. In some places the cell branches may end in "sucker feet" which are closely applied to the walls of small blood vessels. In the peripheral nervous system neuroglial cells are found in the ganglia, forming supporting capsules round the cell bodies. In the nerves themselves the neuroglia cells are greatly modified to form the neurilemmal sheaths.

Ependyma

Lining the ventricles of the brain and the central canal of the spinal cord is a layer of ciliated columnar cells, called the ependyma. From the bases of these cells long processes extend in a radial fashion through the nervous tissue, reaching in some places as far as the meninges. The cells represent primitive neuroglia. The cells covering the choroid plexuses are cubical and have specialized secretory functions.

Microglia

In the central nervous system, particularly in the grey matter, are small branching cells called microglia. These

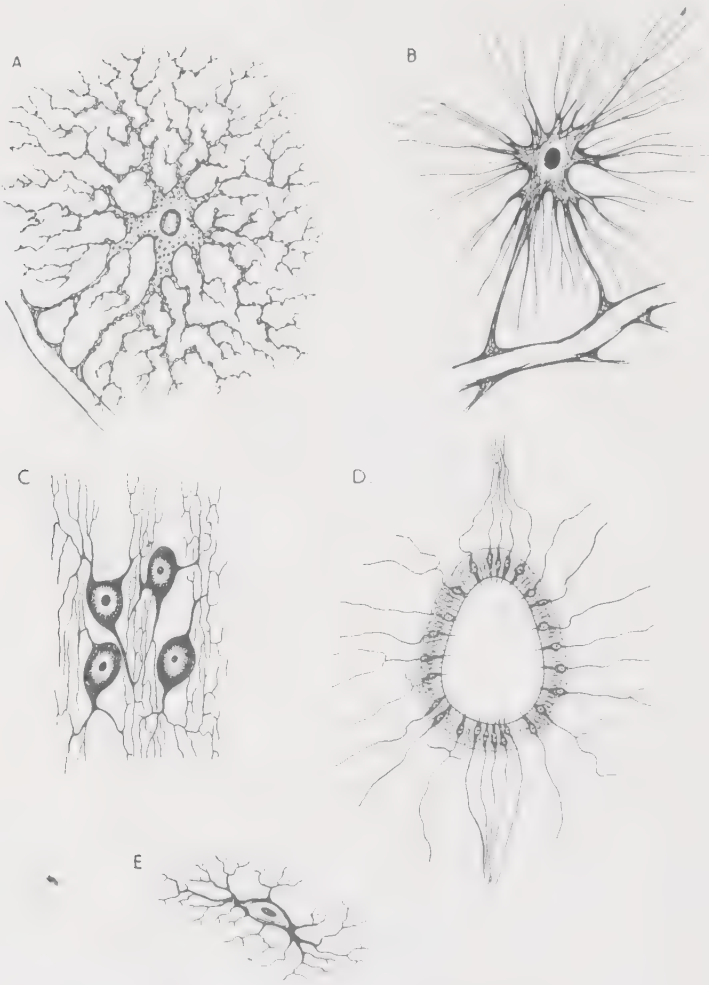


Fig. 57

DIAGRAM OF NEUROGLIA CELLS

A, B and C Various types of neuroglia cells.
D Ependyma. E Microglia cell.

are not true neuroglia cells, but are derived from the histiocytes of the meningeal connective tissue. They penetrate into the nervous tissues during the development of the nervous system. They retain their phagocytic functions and are capable of migrating by amœboid movement.

DEGENERATION AND REGENERATION OF THE NERVOUS TISSUES

At birth the total complement of neurones is present in the nervous system. If any of these is destroyed no replacement can occur as the neurones are incapable of cell division. The neuroglia cells, however, retain the capacity for division. Following an extensive injury to the tissues of the central nervous system these cells proliferate and form a type of scar tissue.

Injury to or disease of the cell body generally results in the death of the whole neurone. Nerve cells may die also from lack of oxygen or from poisoning by various chemical substances. As the cell body degenerates the Nissl's granules disappear and the nucleus becomes displaced from its central position and may be extruded: the cell body swells: but later shrinks and disintegrates: degeneration of the cell body is followed by that of its processes.

Injury to the nerve fibres most commonly occurs in the peripheral nervous system. Degeneration follows rupture of the axon even though the neurilemma remains intact. Degenerative changes occur throughout the fibre distal to the lesion, and extend centrally towards the cell body for at least as far as the next node of Ranvier. If the injury is extensive or close to the cell body the whole neurone may die.

Following the injury the axon rapidly breaks up into short segments and finally into granules: the myelin

sheath disintegrates into fatty droplets which, with the axon granules, are removed by phagocytosis: the neurilemma cells multiply and, retaining contact with each other, remain to mark the original track of the fibre.

The cell body may show secondary degenerative changes, but providing it remains alive regeneration of the fibre can generally take place. The stump of the axon becomes bulbous, and from it numerous protoplasmic threads sprout out and grow into the surrounding tissue. When one of these establishes contact with the original track it begins to grow down it, and the other threads degenerate. The presence of scar tissue may hinder or even prevent regeneration. As the new axon grows the neurilemma re-forms around it and, in medullated fibres, the myelin sheath is laid down later. The new axon grows slowly: 1 mm. a day is estimated as an average rate. If regeneration fails the whole neurone eventually dies. In the central nervous system no regeneration can take place owing to the absence of neurilemmal sheaths.

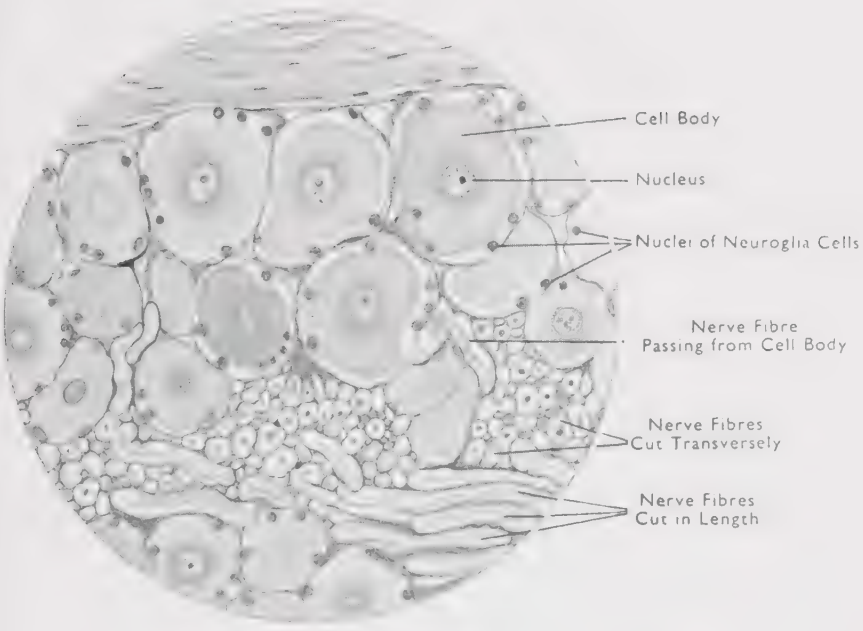


Fig. 58

UNIPOLAR NERVE CELL BODIES. POSTERIOR ROOT GANGLION. × 200.

In section the unipolar cell bodies appear rounded, though mutual compression and shrinkage of the protoplasm during preparation of the tissue may cause some distortion of shape. Each cell body is surrounded by neuroglia cells in the form of a capsule. The nuclei of these cells are generally easily distinguishable. Each cell body gives rise to a single process only, and its point of origin is therefore rarely seen in section. Even where it is visible, as in one of the cells in this drawing, the process cannot be followed as a continuous structure since it coils before leaving the capsule. Having passed from the cell body the process becomes medullated. Many such medullated fibres are shown both in transverse and in longitudinal section.

Fig. 59

MULTIPOLAR NERVE CELL BODIES. SPINAL CORD.
× 130

This drawing shows the cell bodies of the anterior horn of the spinal cord as they appear in section. Each cell body gives rise to numerous processes of which one is an axon and the others are dendrons. The section may pass through a cell body in such a way that several of its processes are shown and it appears typically stellate in shape. On the other hand if only one or two of the cell processes lie in the plane of the section an erroneous impression of the shape of the cell is given. Certain of the cell processes can be followed for some distance from their junction with the cell body, and the branching nature of the dendrons can be seen. In most cases, however, they do not lie in the plane of the section for any great distance. The surrounding tissue consists of the finer branches of cell processes together with neuroglia cells. The processes of these latter cannot be distinguished but the nuclei of several can be seen in the drawing.

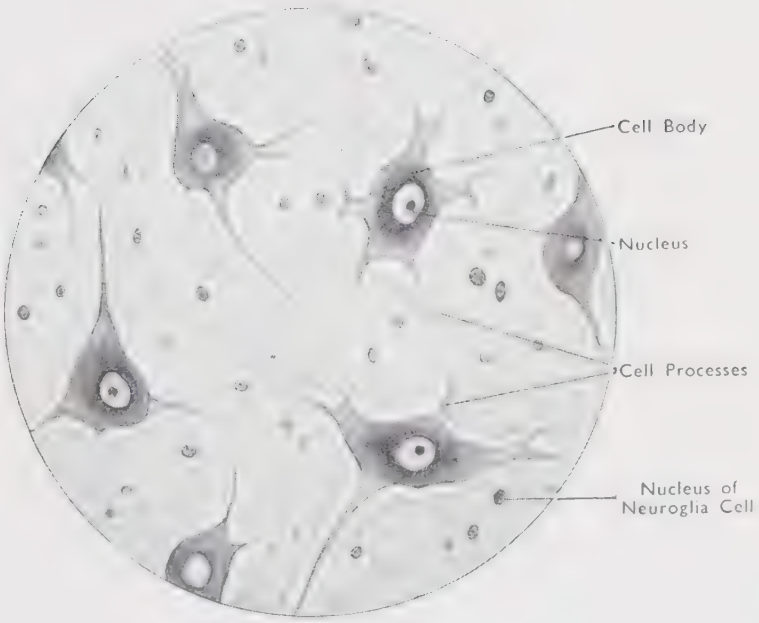

Cell Body
Nucleus
Cell Processes
Nucleus of
Neuroglia Cell

Fig. 60

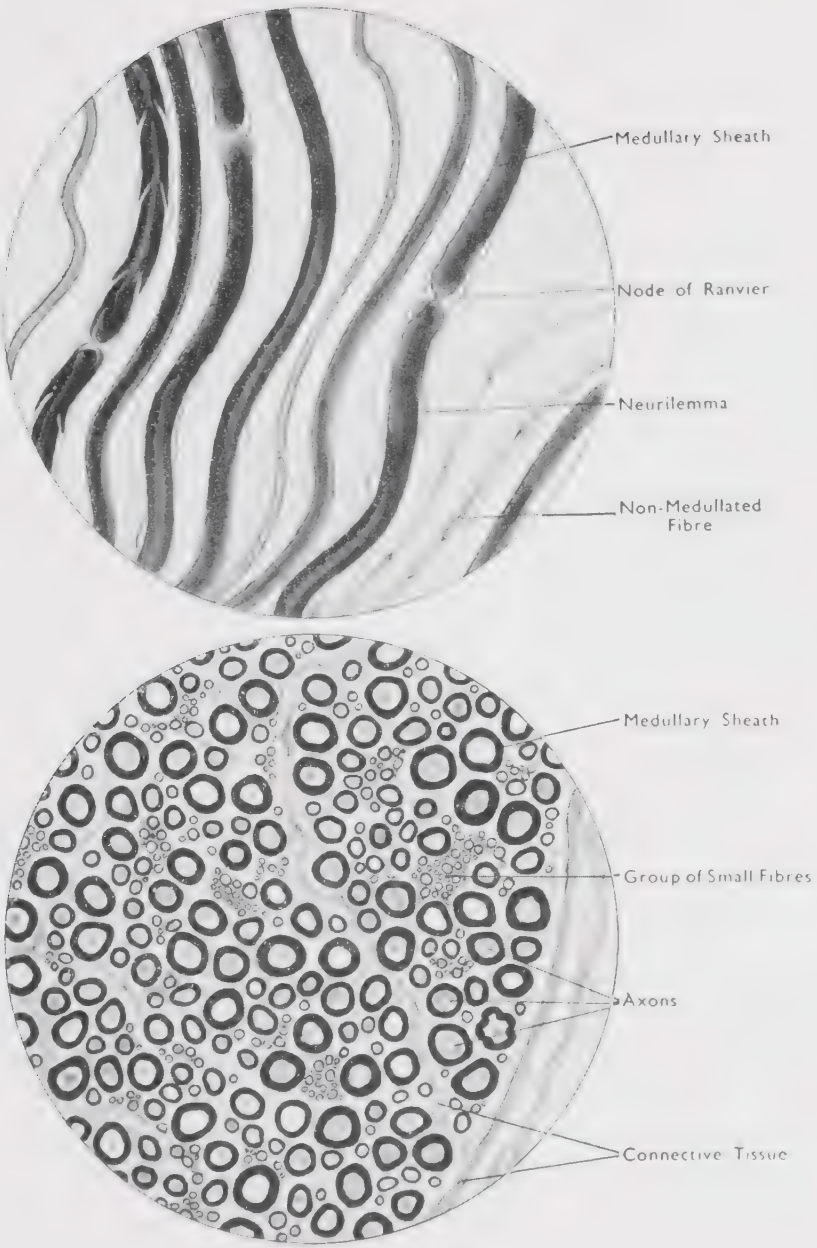
NERVE FIBRES. TEASED. × 210.

The nerve fibres have been teased apart and are therefore more widely separated than in life. The fibres have been treated with osmic acid which blackens the myelin sheaths; thus the medullated fibres are easily distinguishable, but the enclosed axons cannot be seen. The nodes of Ranvier show at intervals as transverse breaks in the continuity of the medullary sheath. Careful inspection may reveal the axon and the neurilemma as they pass uninterruptedly across a node. The preparation of the tissue may cause the appearance of oblique clefts in the medullary sheaths, such as are shown in the larger fibre on the left of the drawing. These clefts are not apparent in the fresh state. It is sometimes possible to identify a few non-medullated fibres. These, not being stained, are difficult to distinguish from the connective tissue strands between the fibres. They are finer than the smallest medullated fibres, and the nuclei of their neurilemma are more numerous and show up more clearly.

Fig. 61

NERVE FIBRES IN TRANSVERSE SECTION. × 280.

In this drawing part of a bundle of nerve fibres is shown cut transversely. The tissue has been treated with osmic acid so that the most obvious structures are the myelin sheaths of the numerous medullated fibres which appear as black rings. Notice the great variety in the size of the fibres. In some, the central axon can be seen in position, but owing to a certain amount of shrinkage of the protoplasm these axons appear smaller than in life; in others, the axons have been dislodged in the cutting of the section. The neurilemma surrounding the medullary sheath is difficult to differentiate from the connective tissue between the fibres. The smaller fibres are grouped together and some are so minute that it is difficult to tell whether they are medullated or not. The connective tissue surrounding the bundle and passing between the fibres can be seen though it is not stained.


Medullary Sheath
Node of Ranvier
Neurilemma
Non-Medullated Fibre
Medullary Sheath
Group of Small Fibres
Axons
Connective Tissue

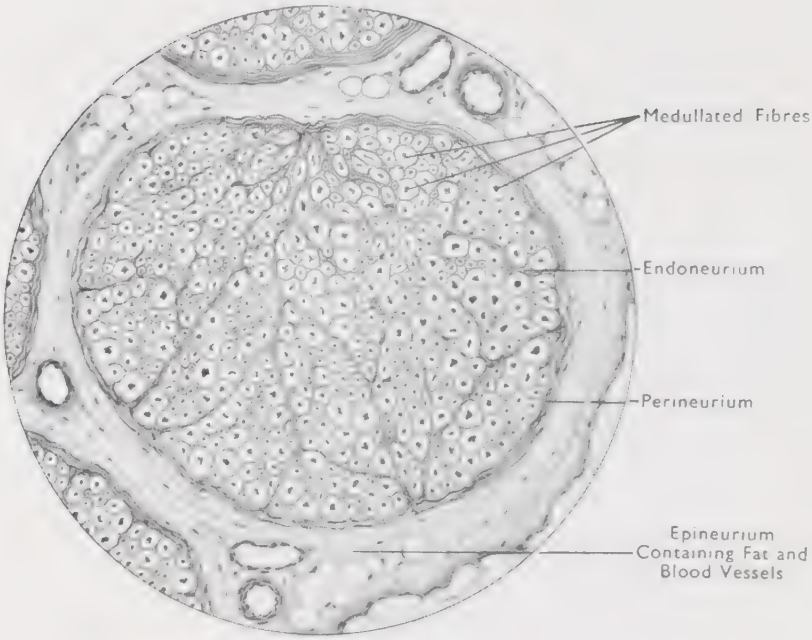


Fig. 62

SPINAL NERVE IN TRANSVERSE SECTION. × 180.

This drawing also shows nerve fibres in transverse section, but in this case all fatty substances have been dissolved during the preparation of the tissue, so that the position of the medullary sheath of each fibre shows as a clear circle. This is surrounded by a fine line, the neurilemma, and the central dot is the axon. Notice how closely the fibres are packed together. The connective tissue sheaths of the nerve are demonstrated by staining. The outer epineurium contains a certain amount of adipose tissue and some blood vessels. The perineurium surrounding each of the nerve bundles is a more concentrated layer of connective tissue arranged in lamellæ. The endoneurium is present within the fibre bundles passing between the individual fibres.

Up to this point the illustrations appended at the end of each chapter have been of the various body tissues dealt with in the respective chapters. The following illustrations are of sections of organs: the purpose of which is to show the integration of the various tissues in their structure and to give some slight idea of the positions and relationship of the tissues in the different organs.

Fig. 63

SKIN OF THE PALM OF THE HAND

VERTICAL SECTION. × 35

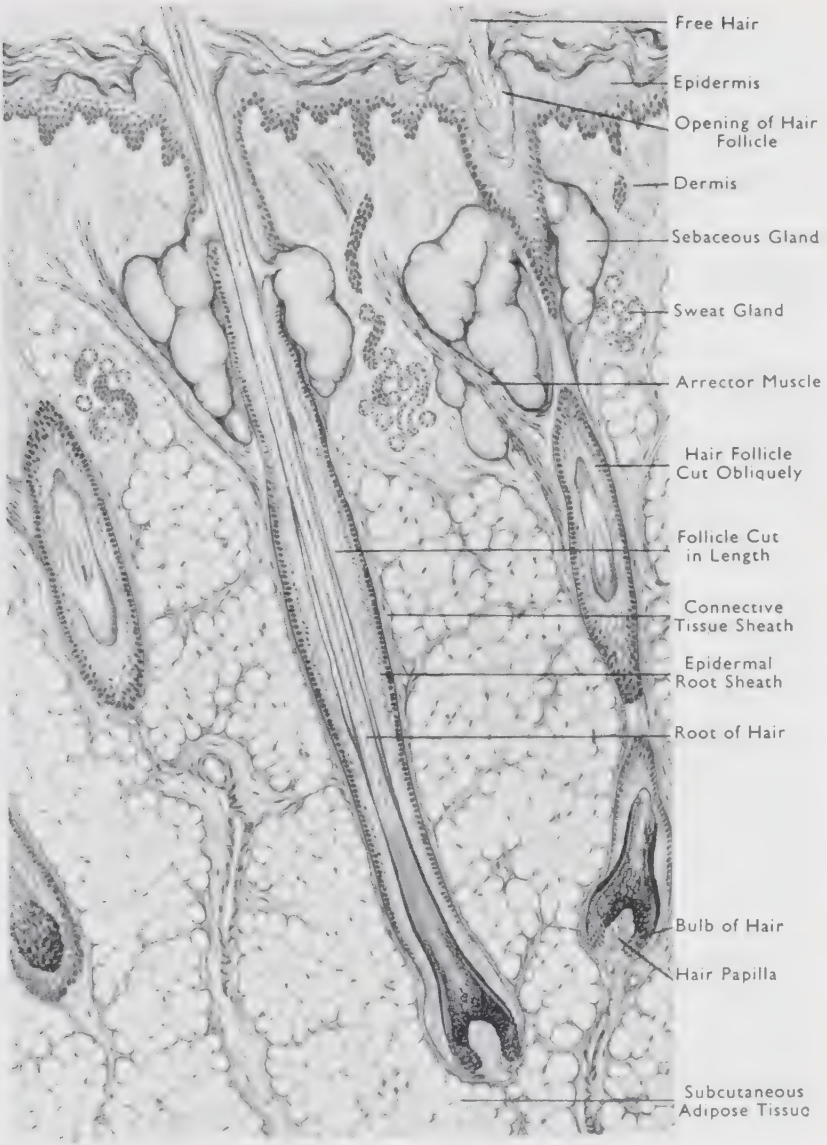


Fig. 64

SCALP

VERTICAL SECTION. × 30

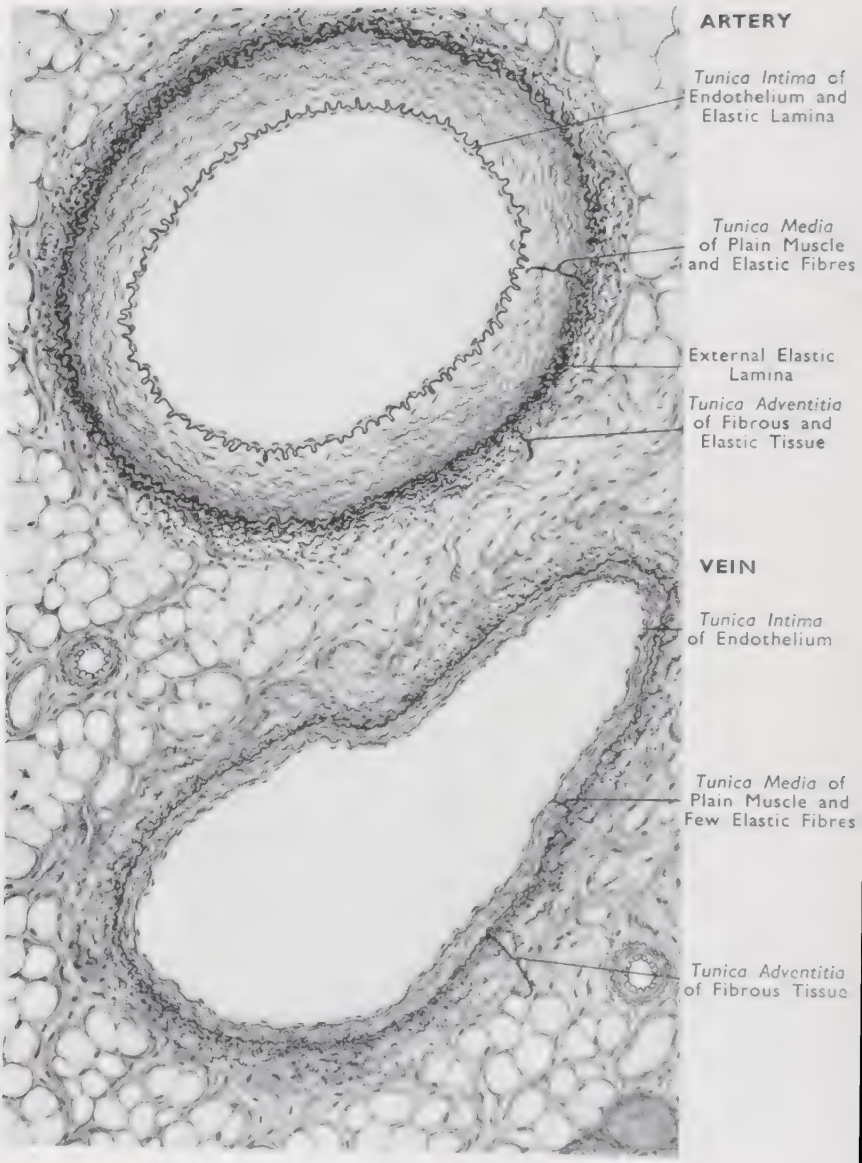


Fig. 65

MEDIUM-SIZED ARTERY AND VEIN

TRANSVERSE SECTION. 90

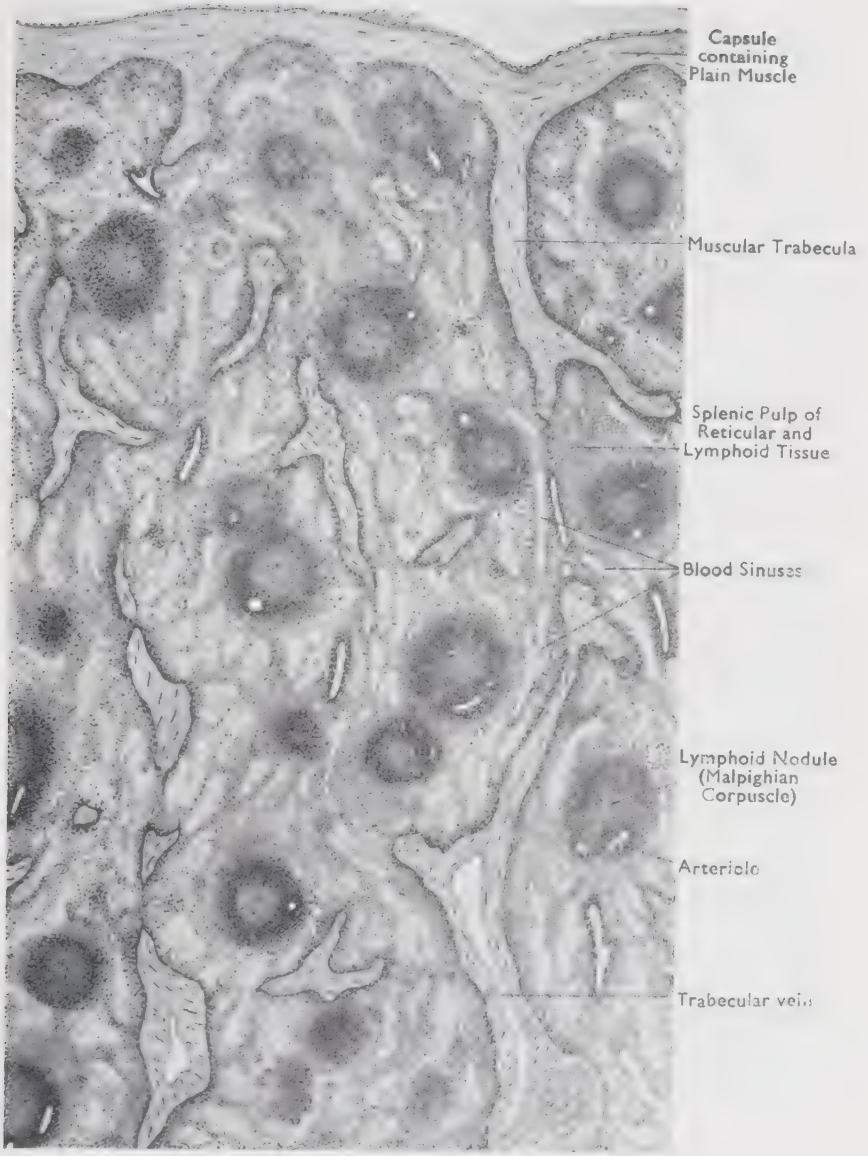


Fig. 66

SECTION OF SPLEEN. 35

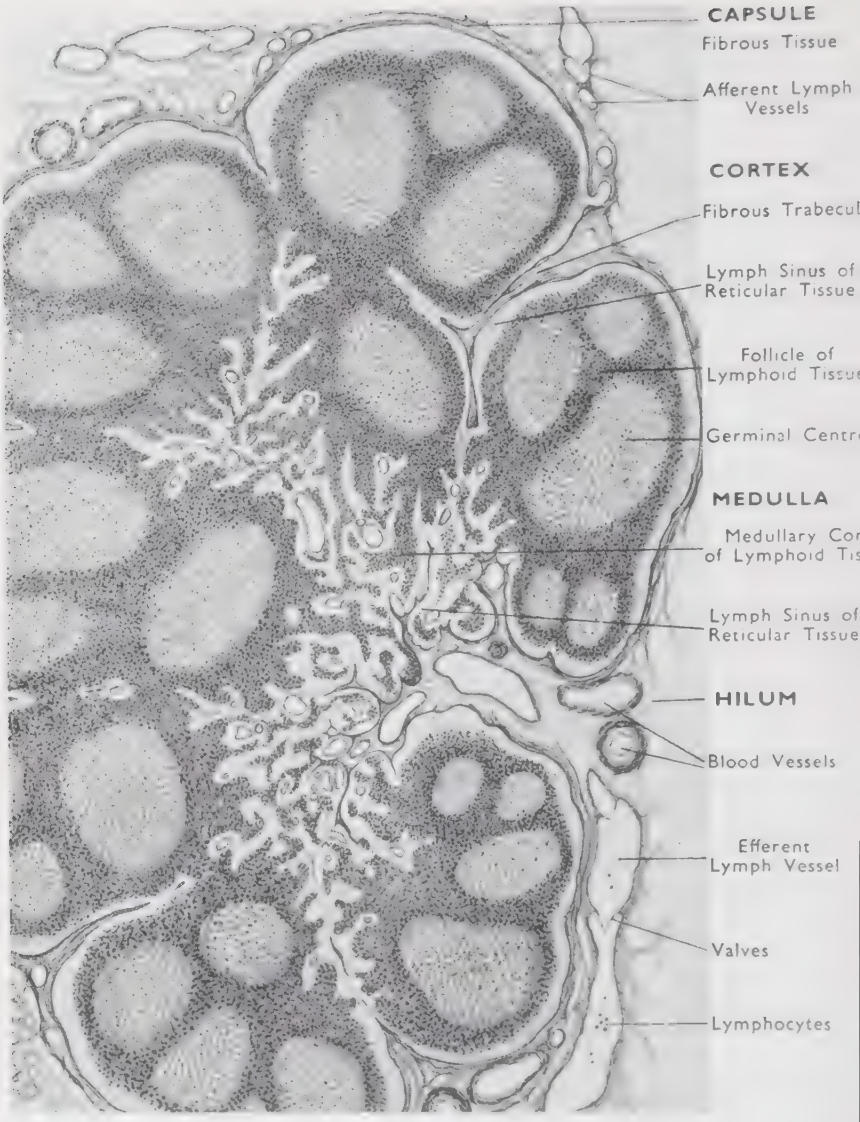


Fig. 67

LYMPH GLAND

LONGITUDINAL SECTION. × 45

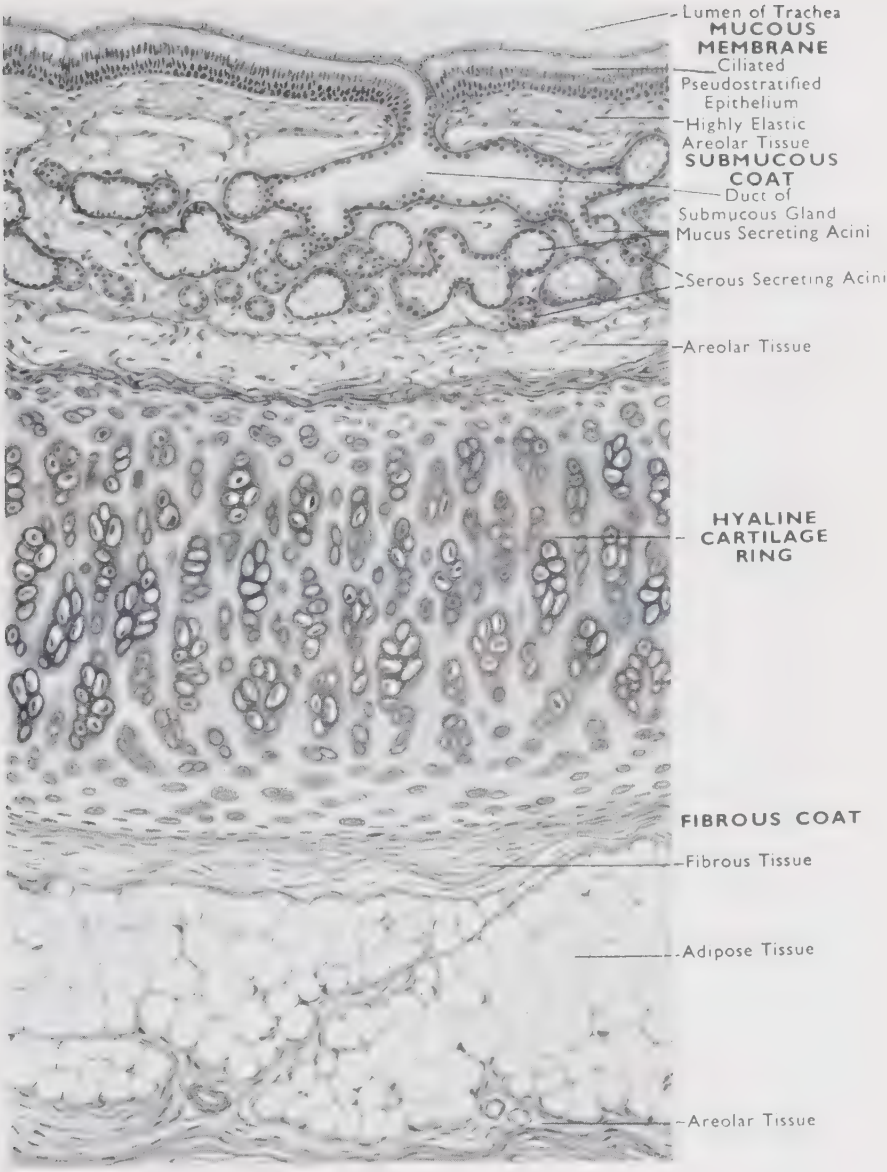


Fig. 68. **TRACHEA**

TRANSVERSE SECTION THROUGH CARTILAGE RING IN ANTERIOR PART. × 115
IN POSTERIOR ONE-FIFTH THE CARTILAGE IS ABSENT, ITS PLACE BEING TAKEN
BY FIBROUS TISSUE CONTAINING INVOLUNTARY MUSCLE

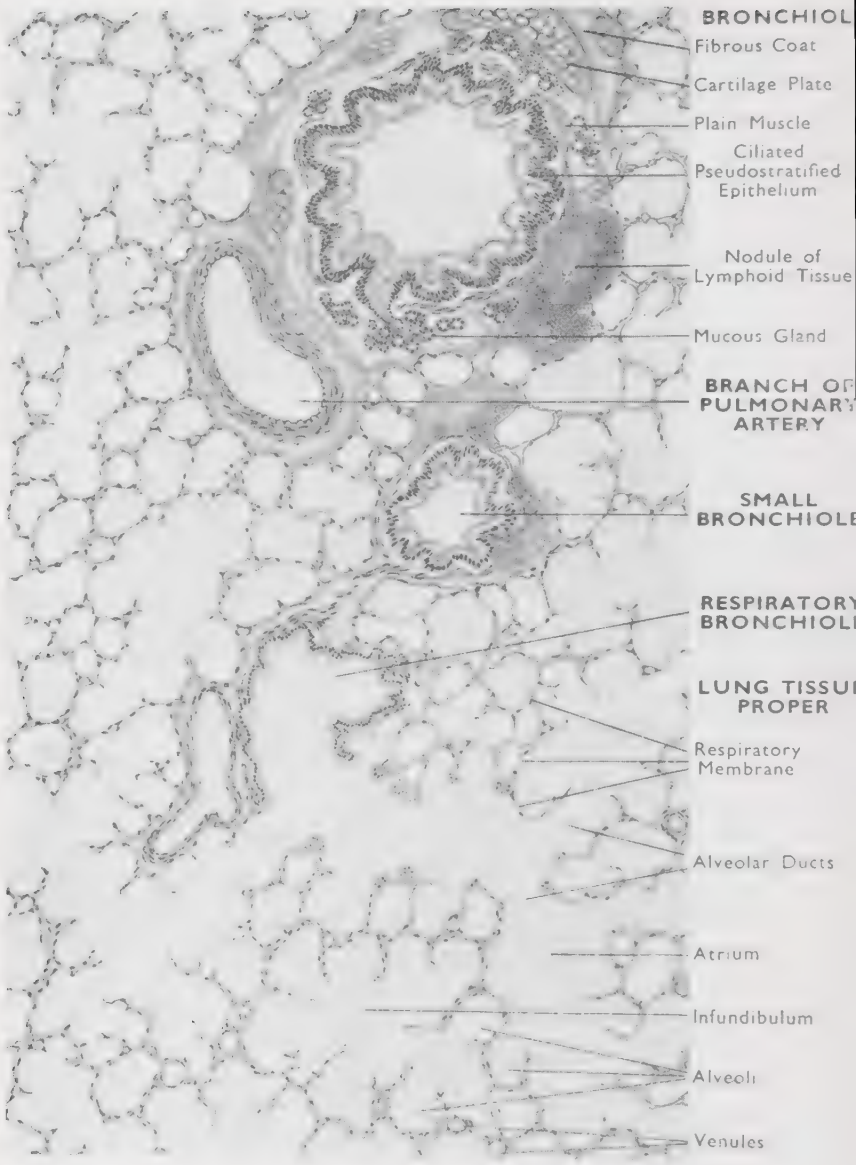


Fig. 69

SECTION OF LUNG AND BRONCHIOLES. × 65

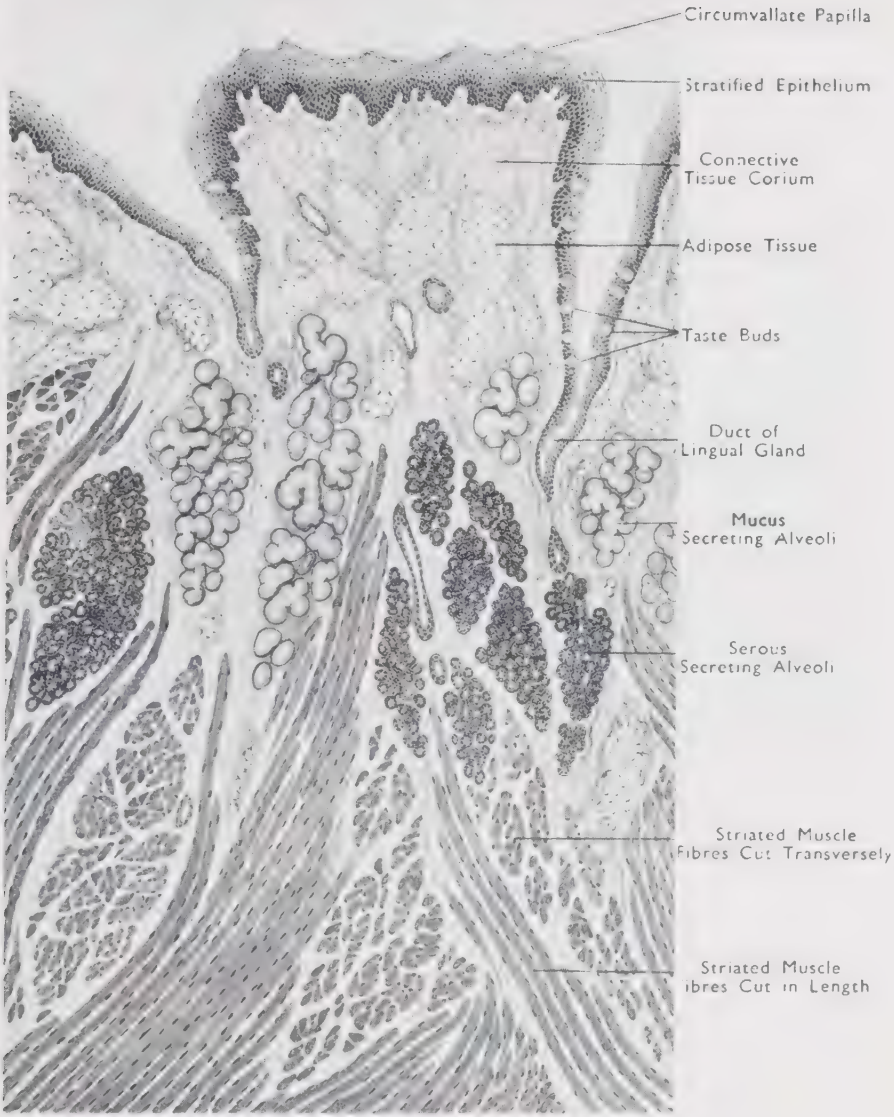


Fig. 70

POSTERIOR PART OF TONGUE

VERTICAL SECTION THROUGH CIRCUMVALLATE PAPILLA ON DORSAL SURFACE

30

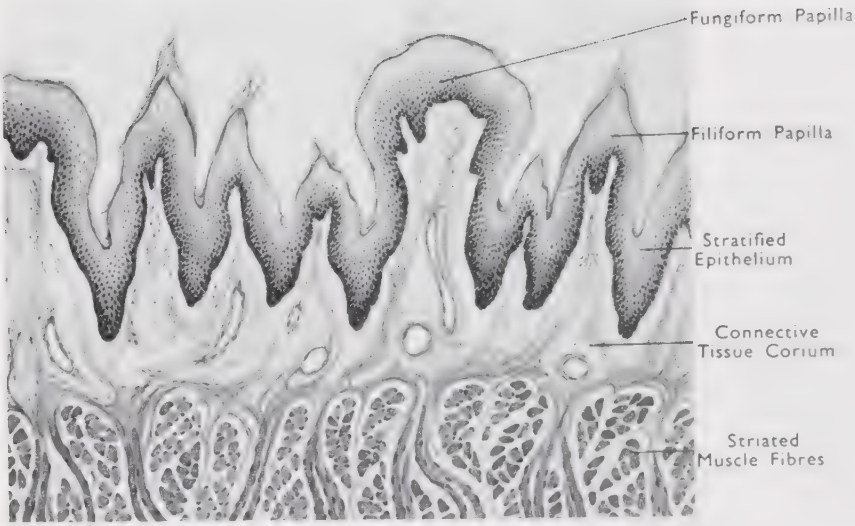


Fig. 71

ANTERIOR PART OF TONGUE

VERTICAL SECTION THROUGH DORSAL SURFACE. × 40

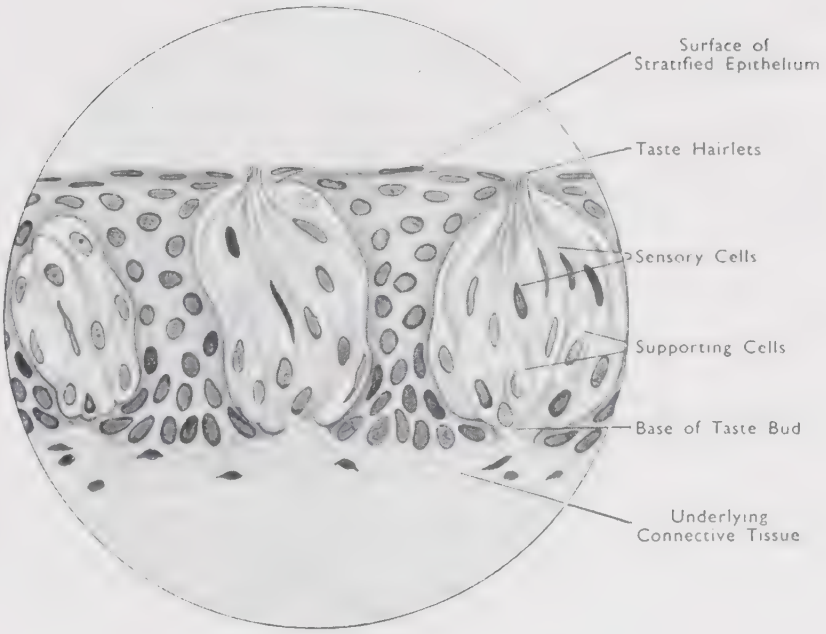


Fig. 72

SECTION OF TASTE BUDS
IN STRATIFIED EPITHELIUM OF THE TONGUE. × 390

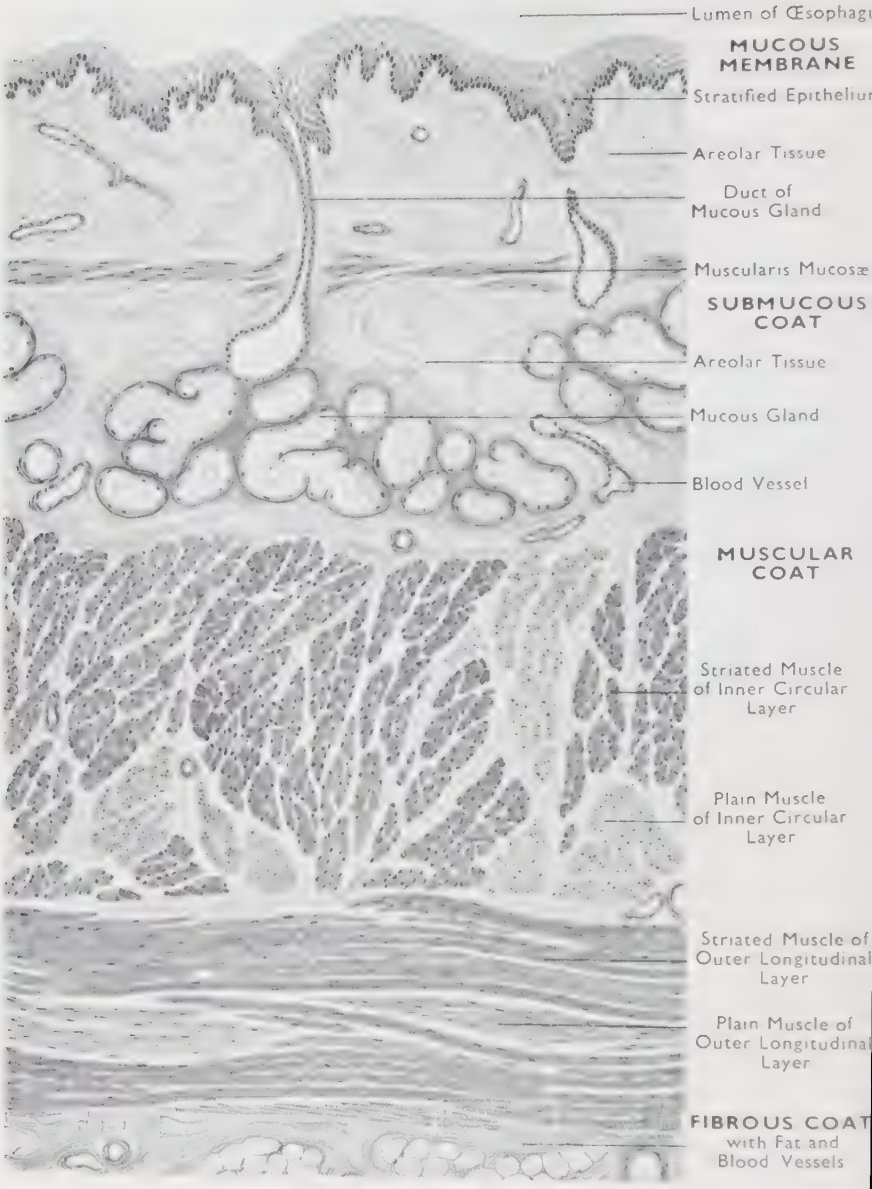


Fig. 73

MIDDLE THIRD OF ŒSOPHAGUS

LONGITUDINAL SECTION. × 30

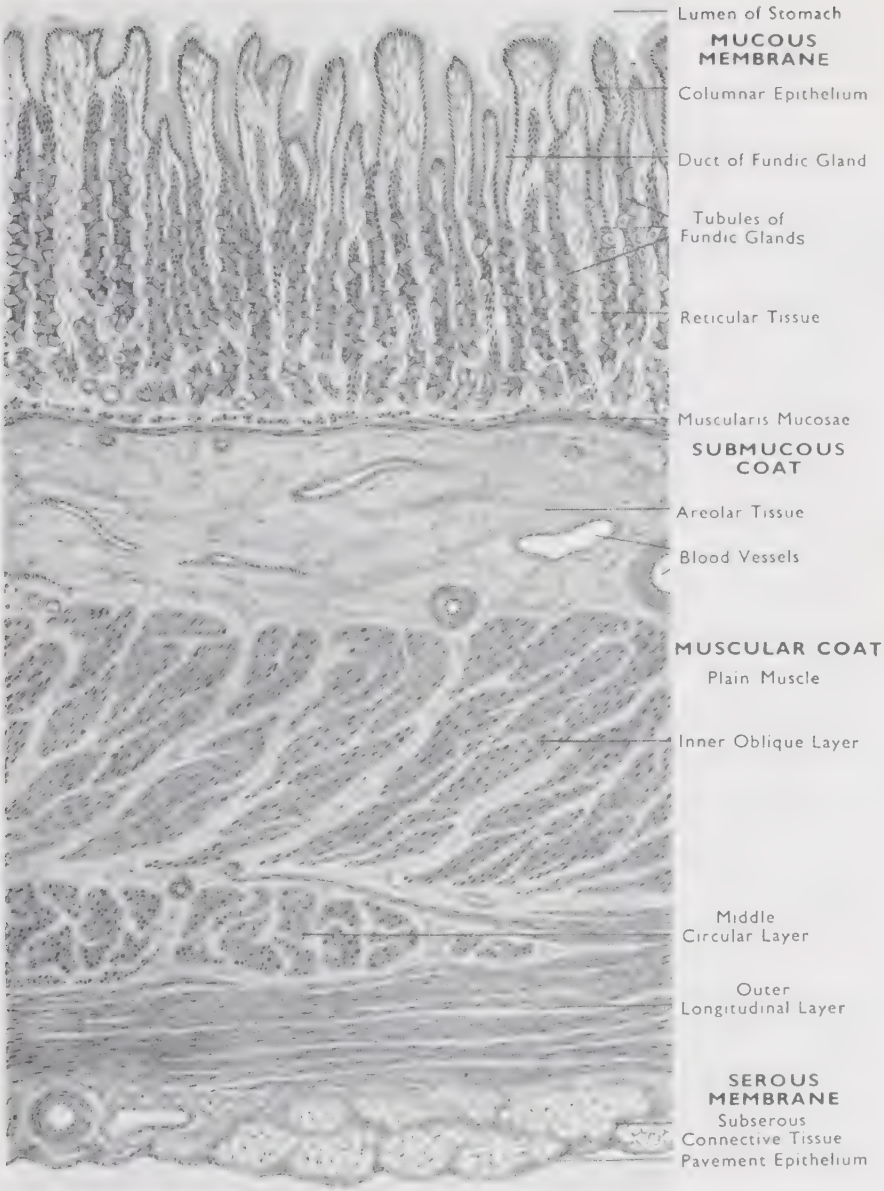


Fig. 74. **FUNDUS OF STOMACH**

LONGITUDINAL SECTION. × 70. IN THE PYLORIC REGION THE OBLIQUE MUSCLE LAYER IS ABSENT WHILE THE CIRCULAR LAYER IS GREATLY THICKENED: THE GLANDS, ALSO, DIFFER IN APPEARANCE

Fig. 75

GLANDS OF THE STOMACH

LONGITUDINAL SECTION. × 160

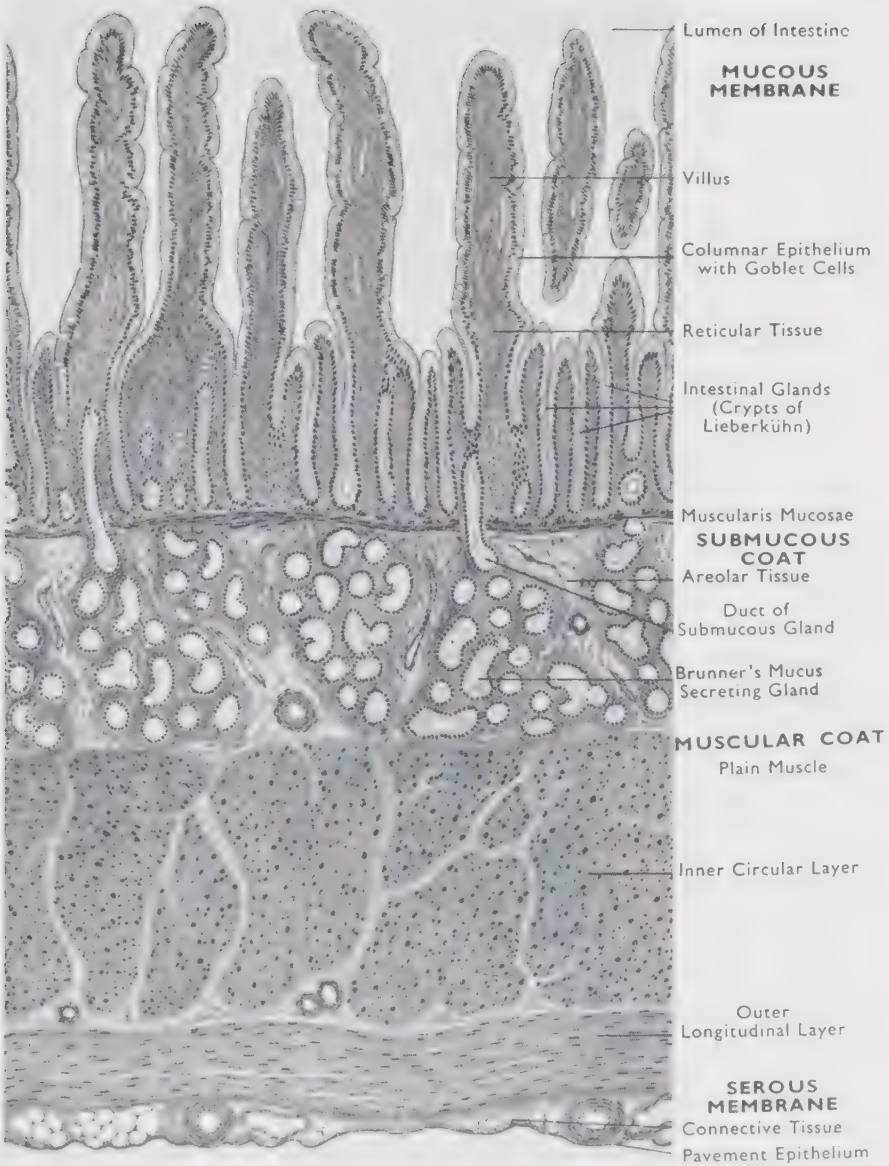


Fig. 76. **DUODENUM**
LONGITUDINAL SECTION. × 70

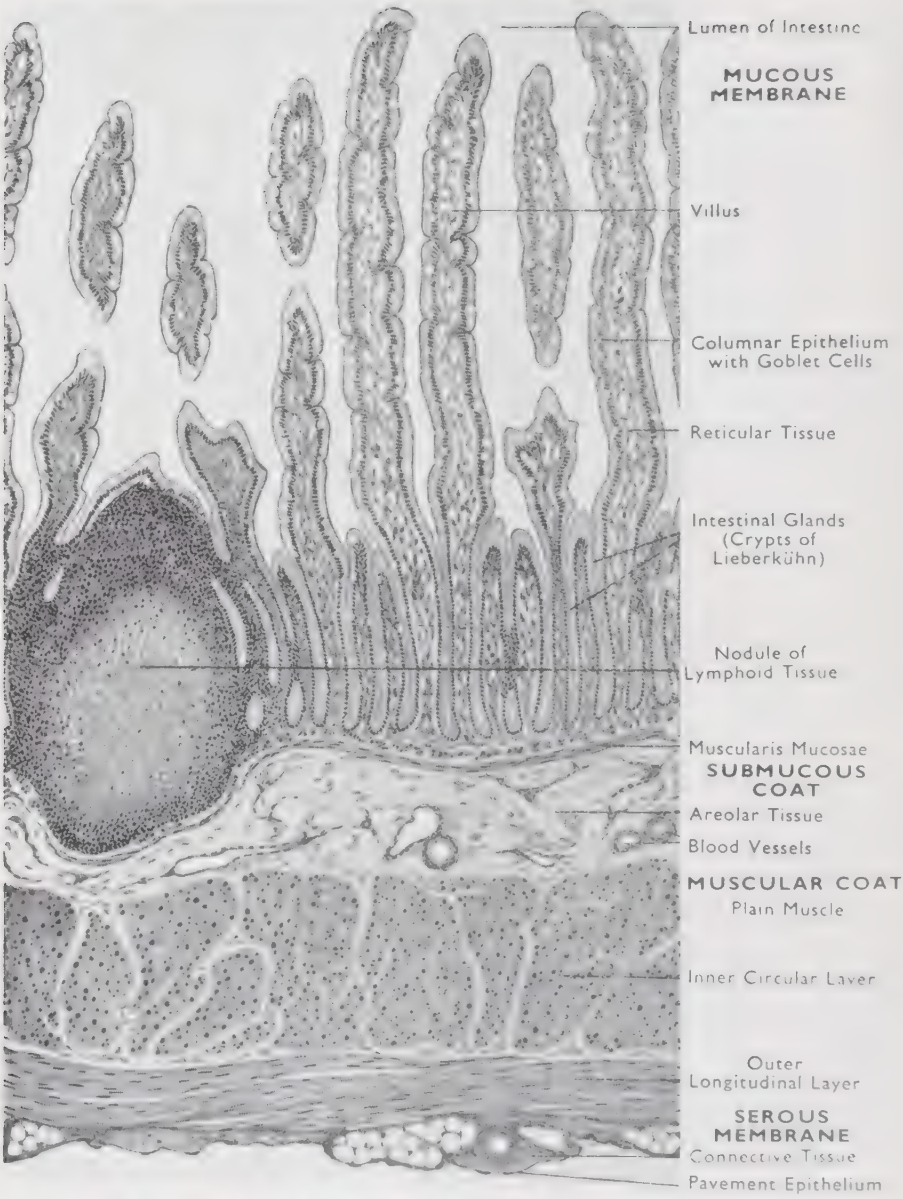


Fig. 77. **ILEUM SHOWING SOLITARY LYMPH NODULES**

LONGITUDINAL SECTION. 60. LYMPH NODES ARE PRESENT ALSO IN THE MUCOUS MEMBRANE OF OTHER PARTS OF THE INTESTINES AND IN THE STOMACH

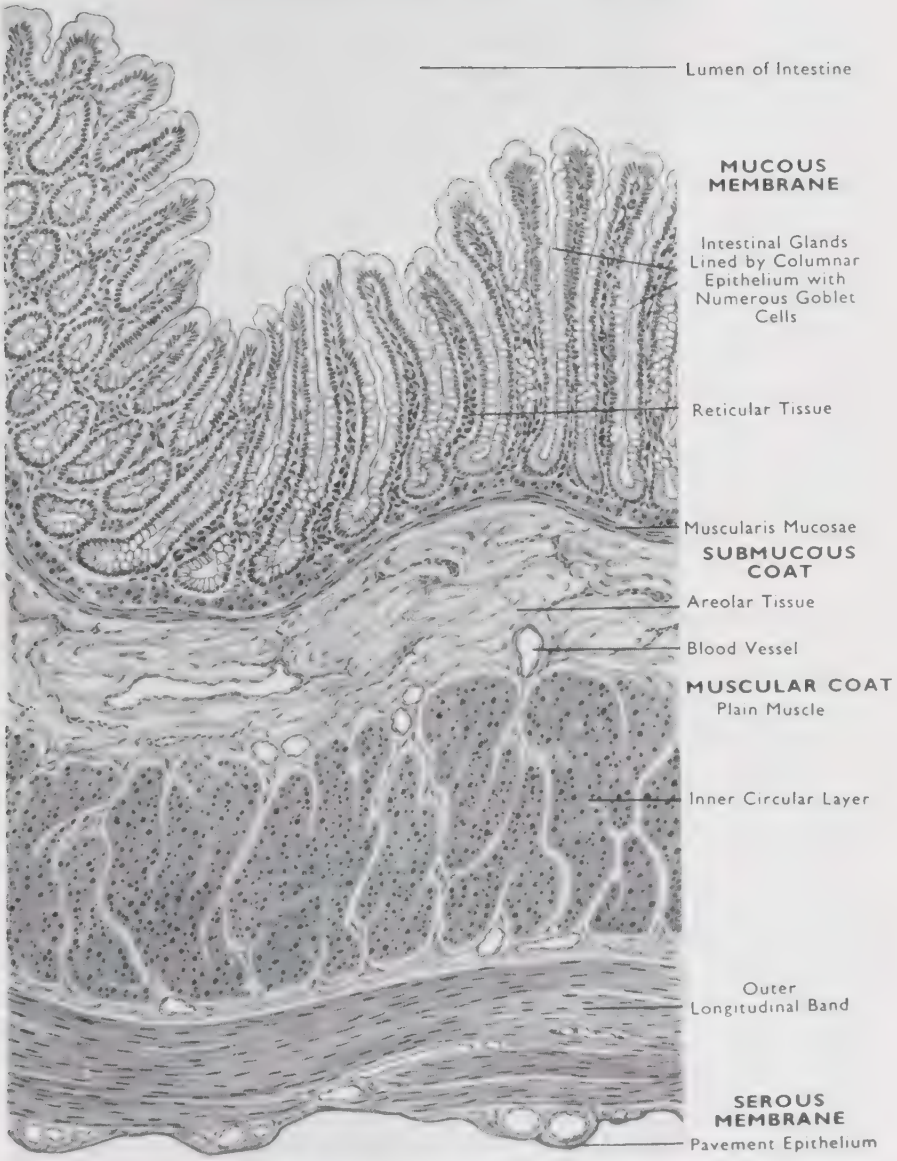


Fig. 78. **LARGE INTESTINE**

LONGITUDINAL SECTION. 80. THE OUTER MUSCLE COAT IS ARRANGED IN THREE DISTINCT BANDS, NOT IN A CONTINUOUS LAYER

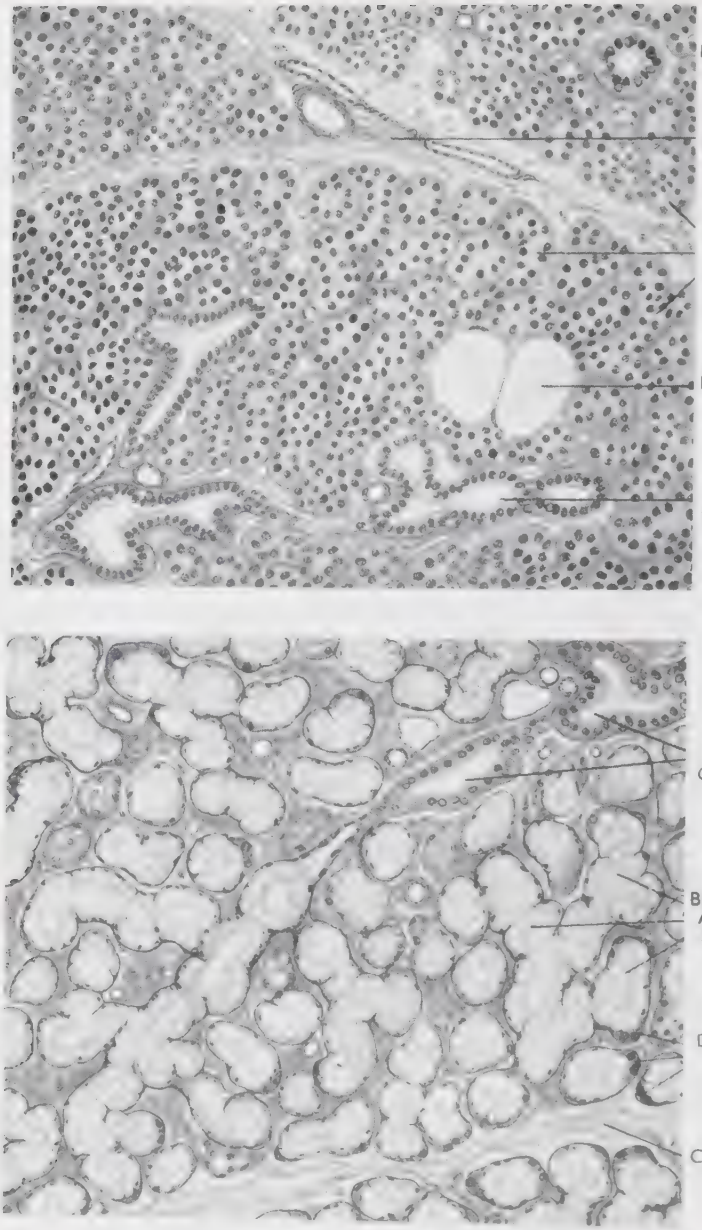


Fig. 79. **SECTIONS OF SALIVARY GLANDS**

THE PAROTID GLAND (125) IS COMPOSED MAINLY OF SEROUS SECRETING ALVEOLI, THE SUBLINGUAL GLAND (110) OF MUCUS SECRETING ALVEOLI WITH SOME SEROUS DEMILUNES, AND THE SUBMAXILLARY GLAND OF BOTH SEROUS AND MUCOUS SECRETING ALVEOLI. ALL ARE COMPOUND TUBULO-ALVEOLAR GLANDS

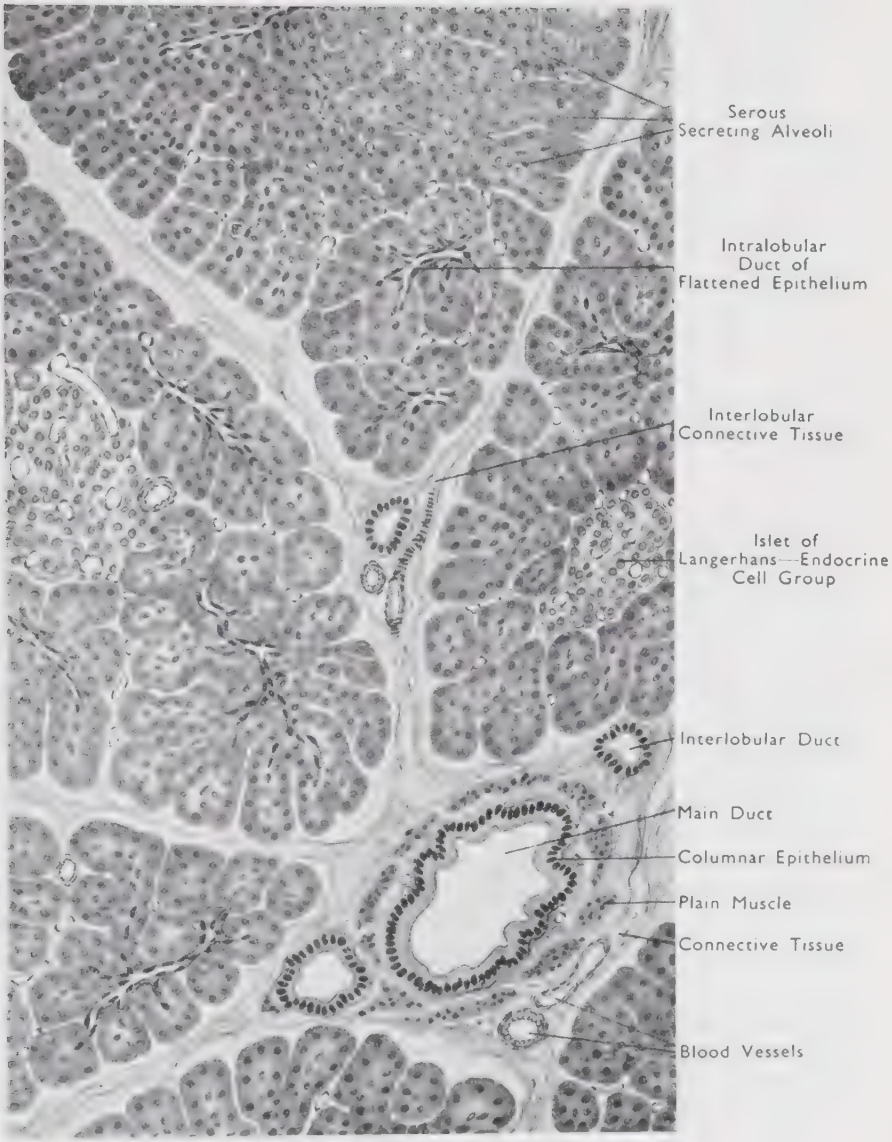


Fig. 80

SECTION OF PANCREAS. × 190

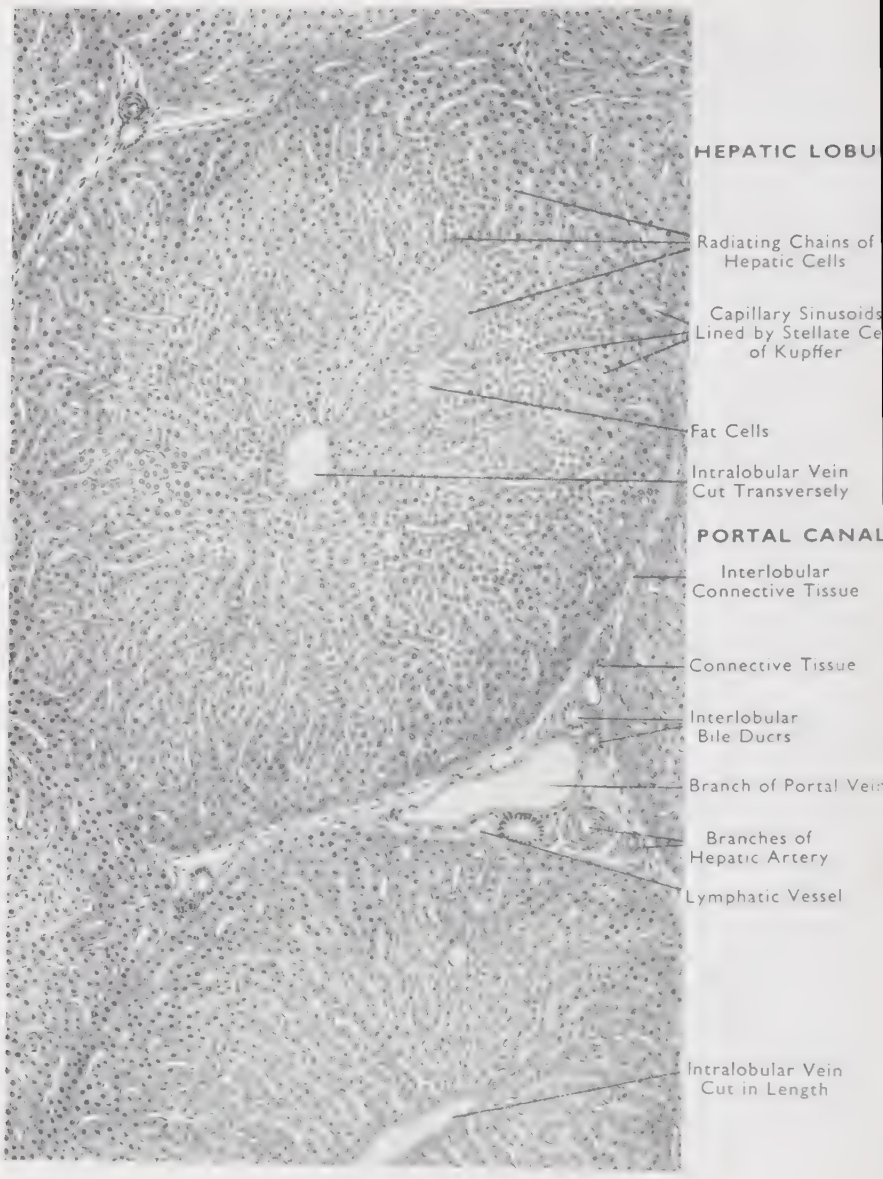


Fig. 81

SECTION OF LIVER (CAT). × 75

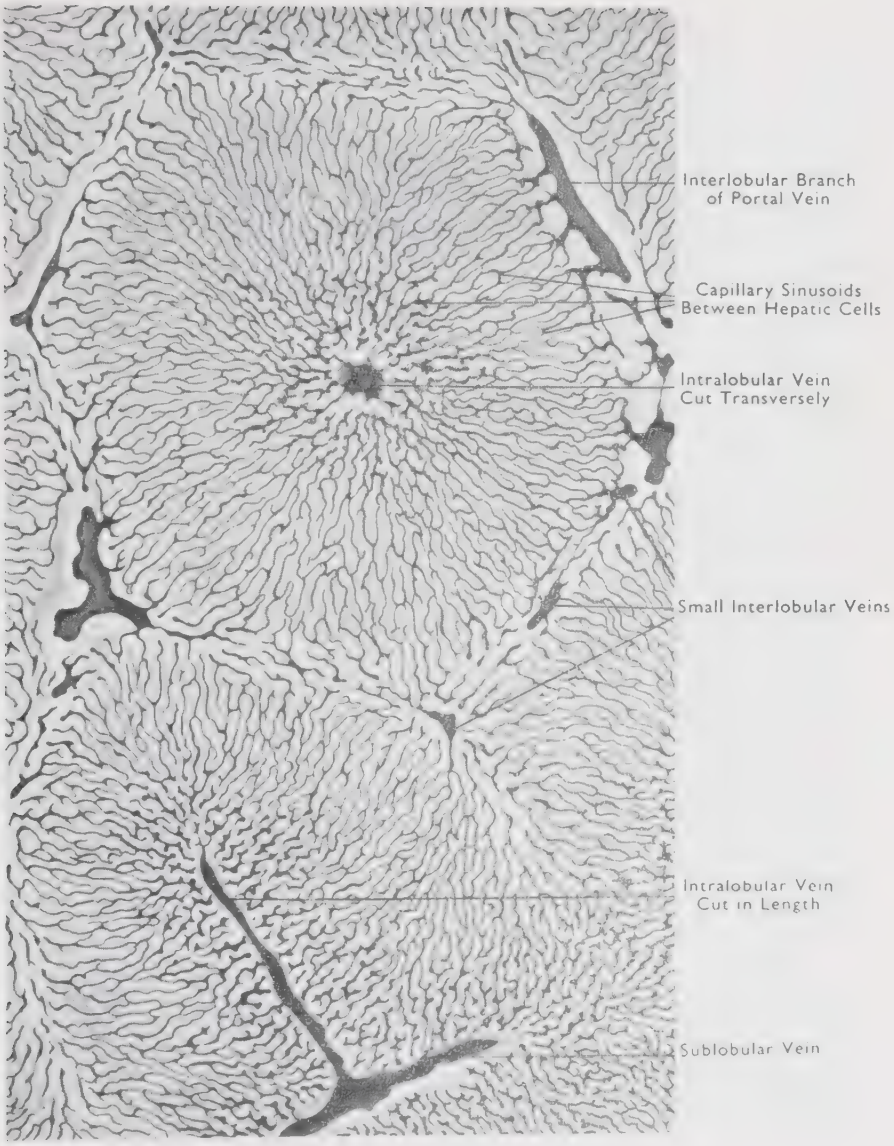


Fig. 82

SECTION OF LIVER

WITH BLOOD VESSELS INJECTED (RABBIT). × 60

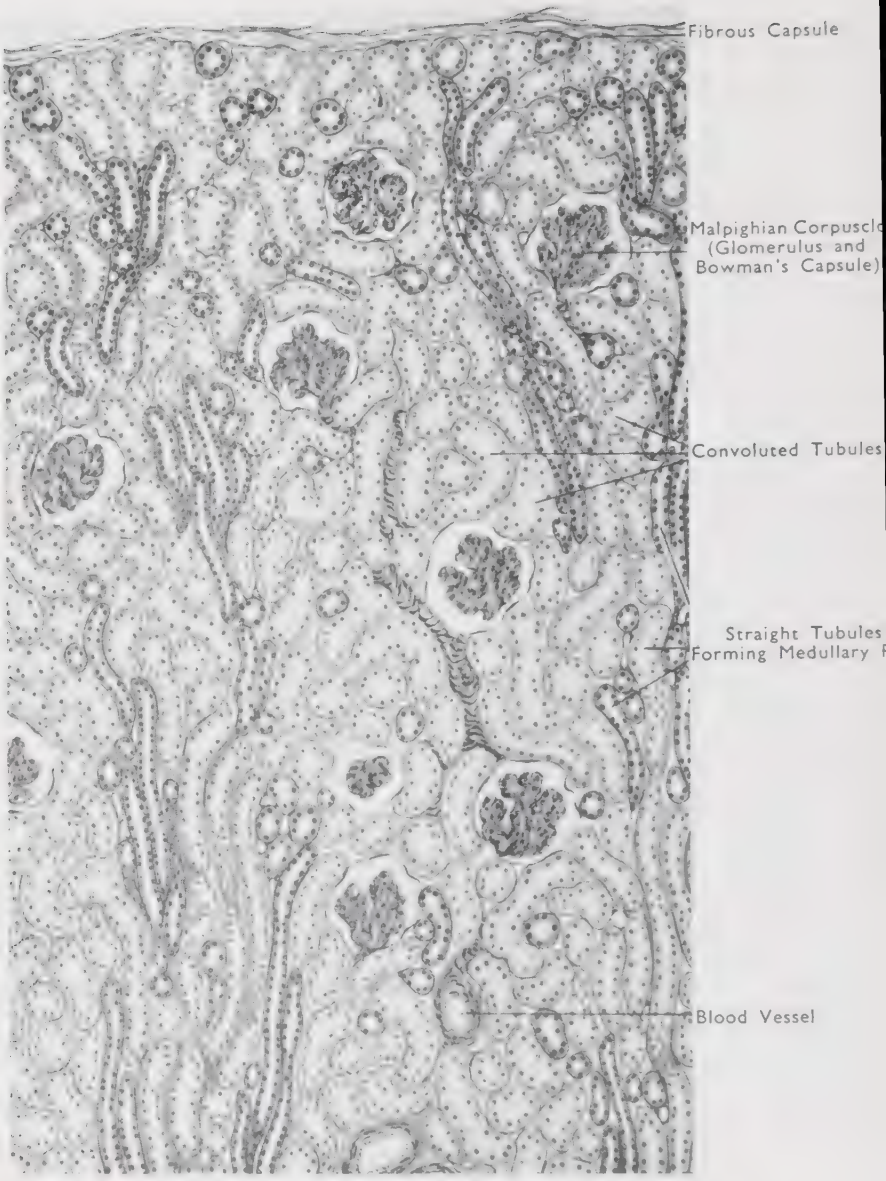


Fig. 83

KIDNEY CORTEX

VERTICAL SECTION. × 65

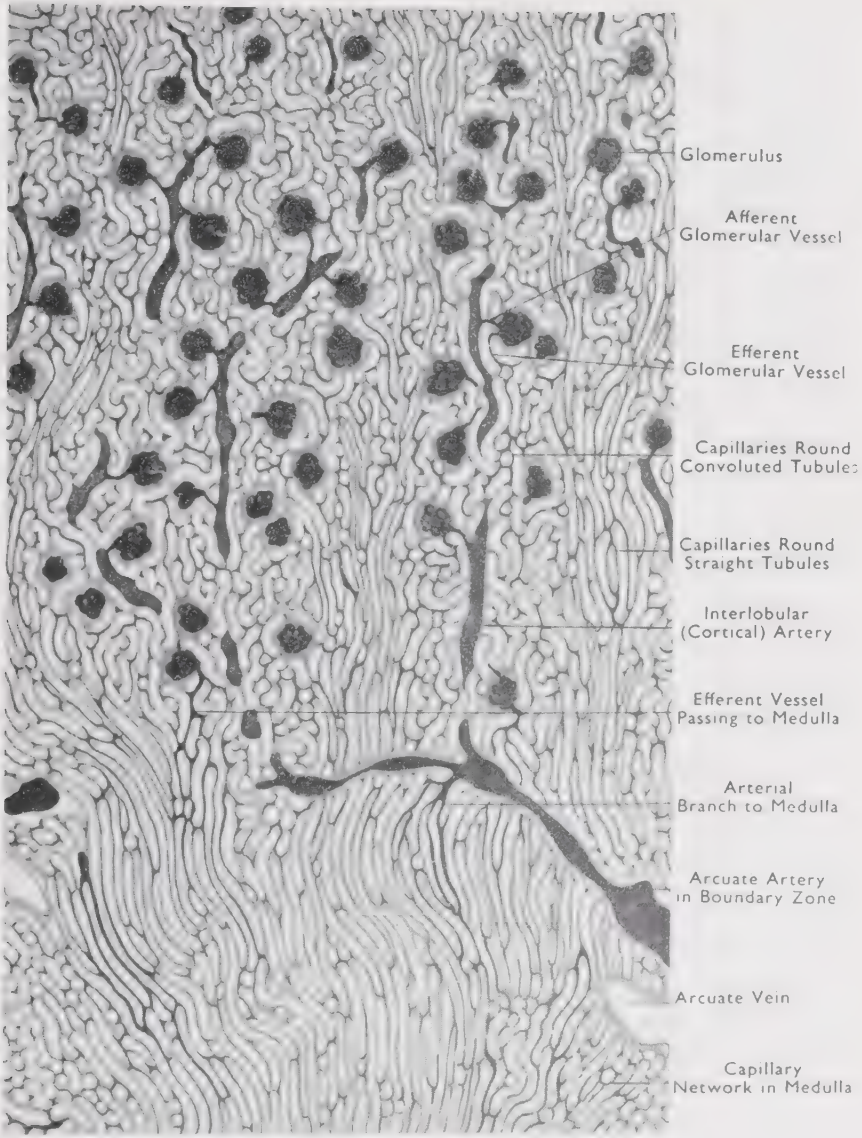


Fig. 84

SECTION OF KIDNEY CORTEX
WITH BLOOD VESSELS INJECTED. × 30

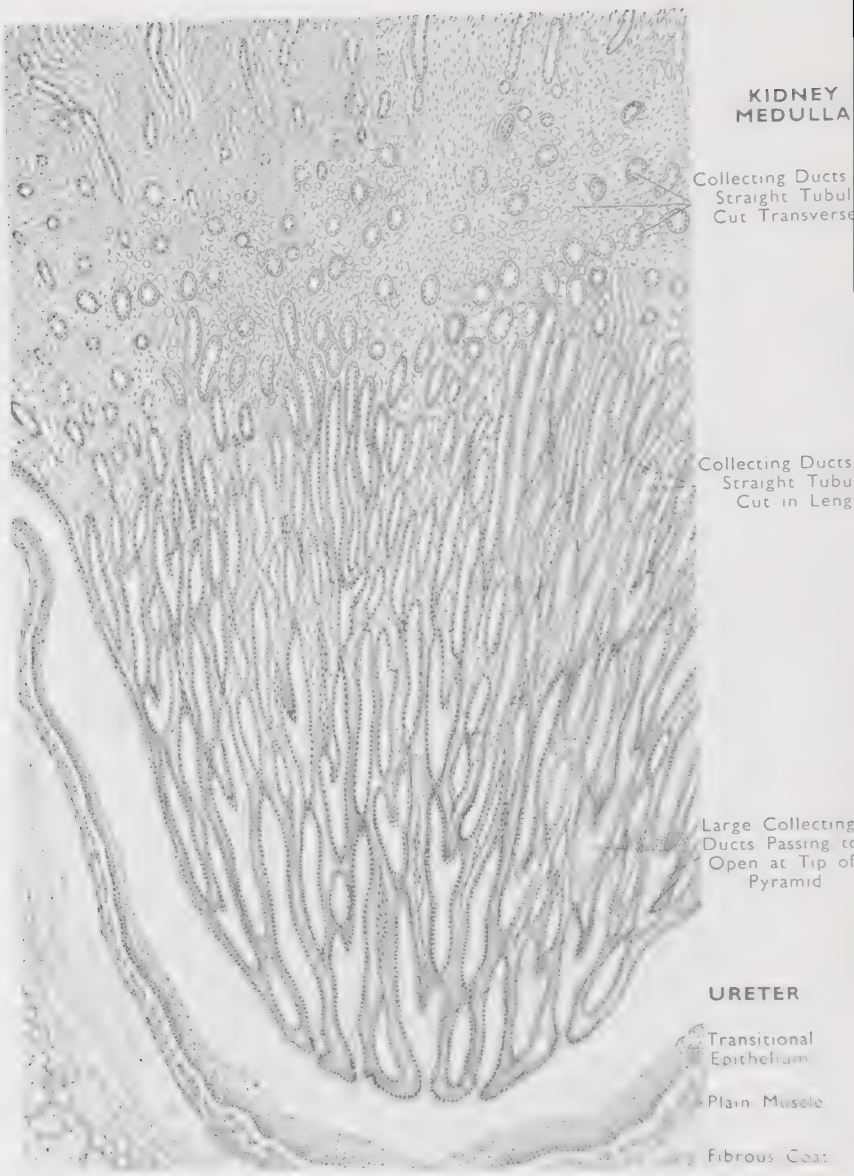


Fig. 85

SECTION OF KIDNEY MEDULLA AND CALYX OF PELVIS OF URETER.
× 35

Fig. 86

SECTION OF URINARY BLADDER. × 65

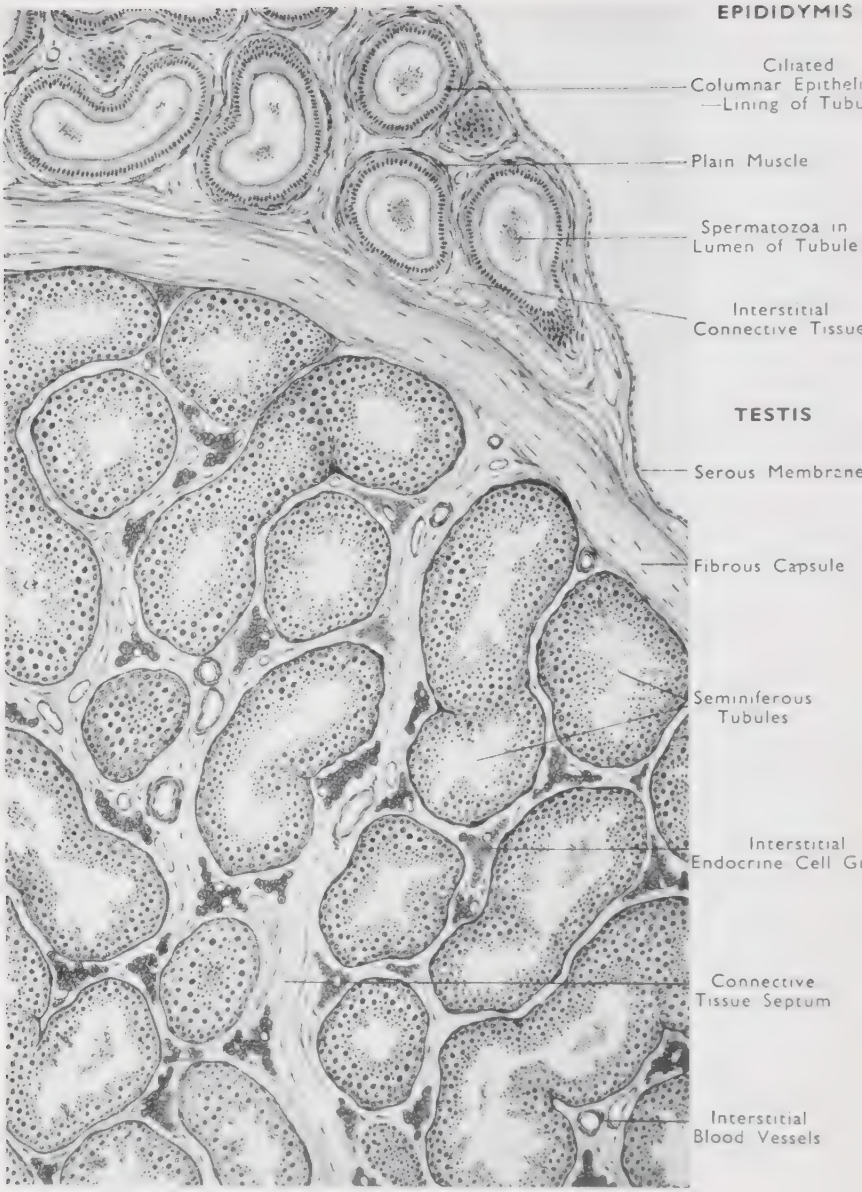


Fig. 87

SECTION OF TESTIS AND EPIDIDYMIS (CAT). × 65

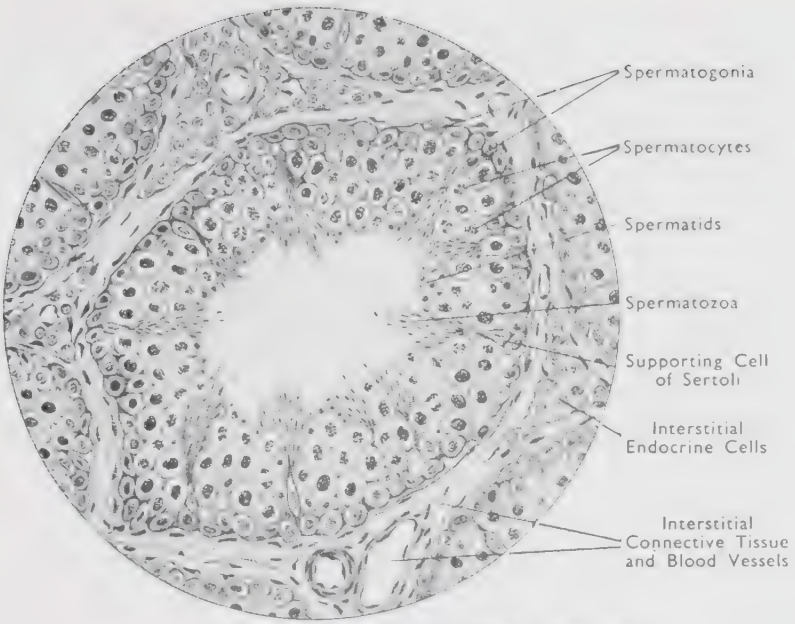


Fig. 88. **SECTION OF TESTIS TUBULES** SHOWING SPERMATOGENESIS (CAT). × 185

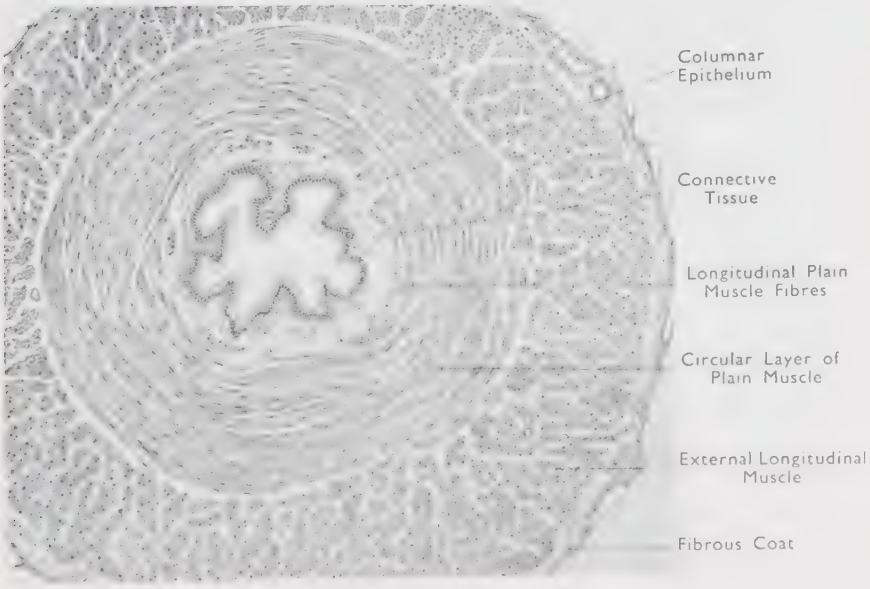


Fig. 89. **VAS DEFERENS.** TRANSVERSE SECTION. × 25

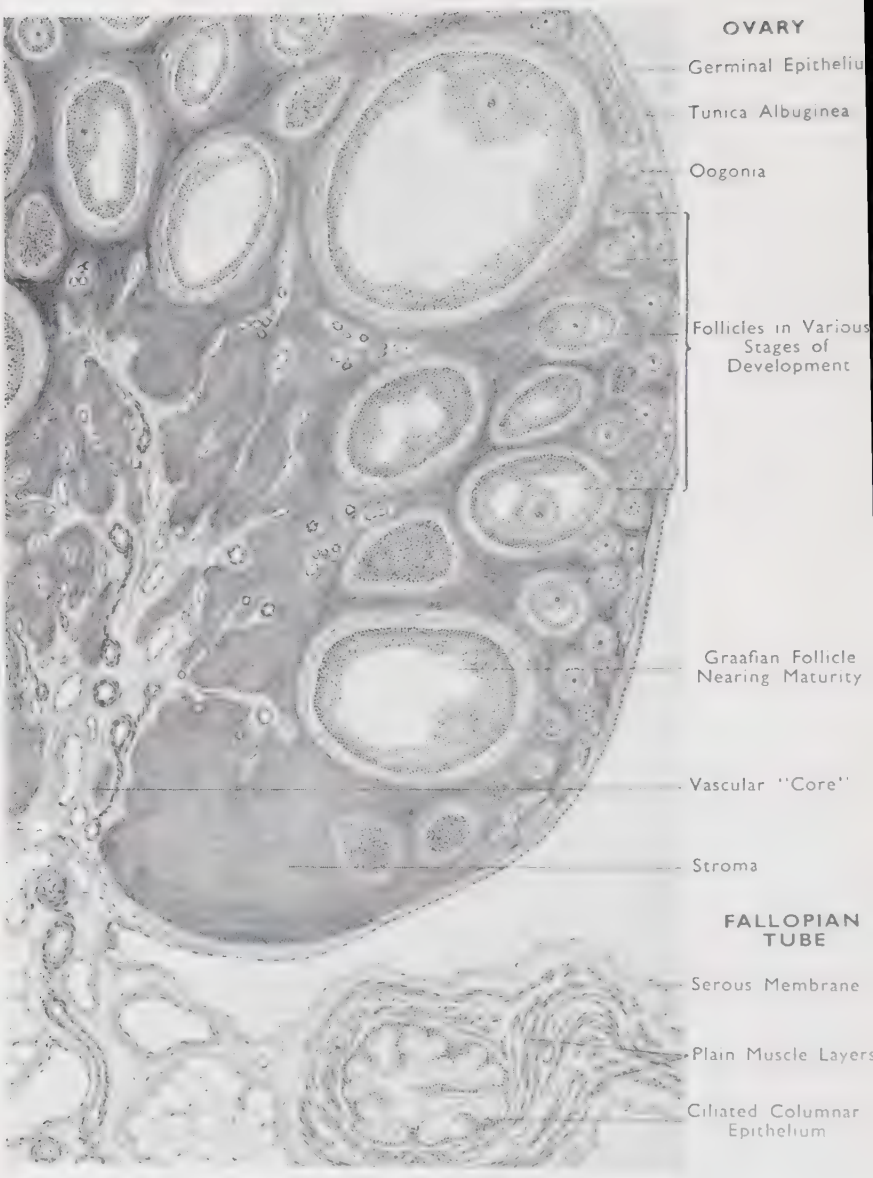


Fig. 90

SECTION OF OVARY AND FALLOPIAN TUBE (CAT). × 45

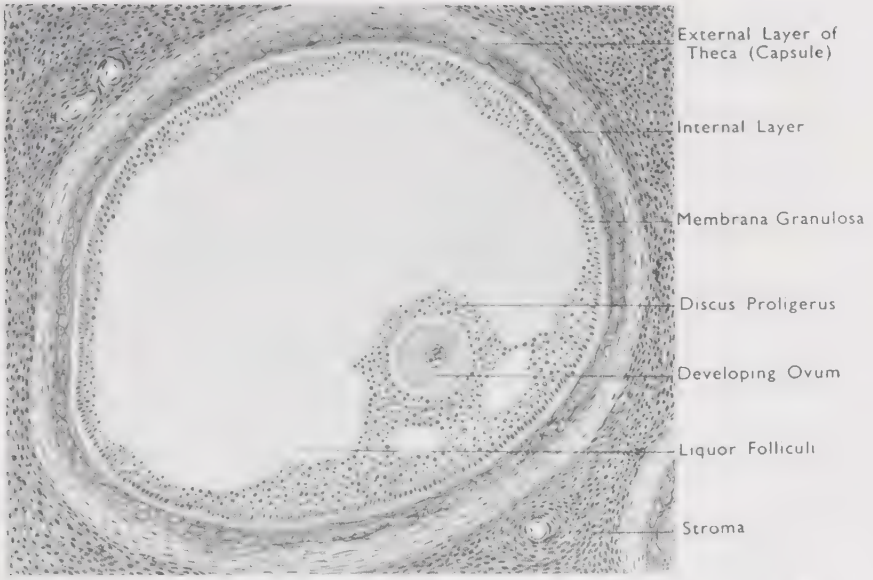


Fig. 91. **SECTION OF MATURING GRAAFIAN FOLLICLE** (CAT). × 90

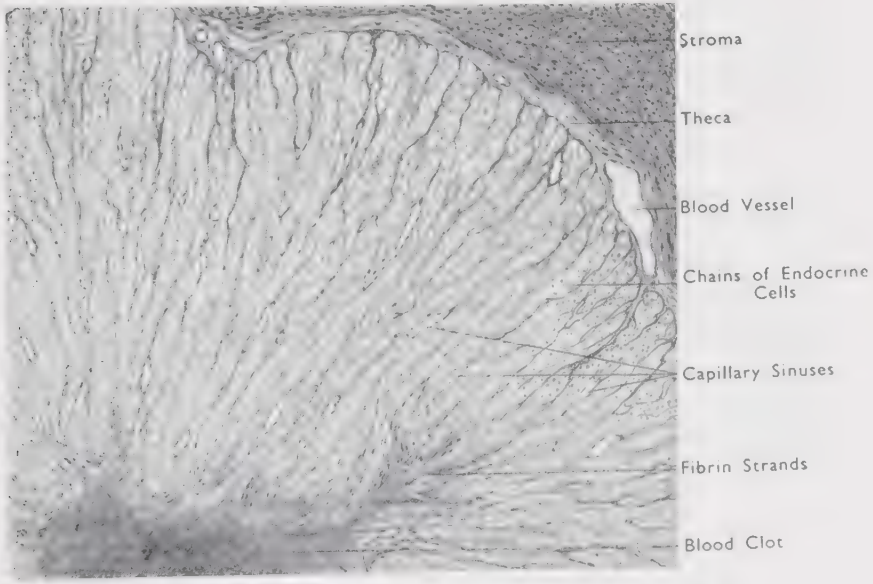


Fig. 92. **SECTION OF CORPUS LUTEUM** (CAT). × 50

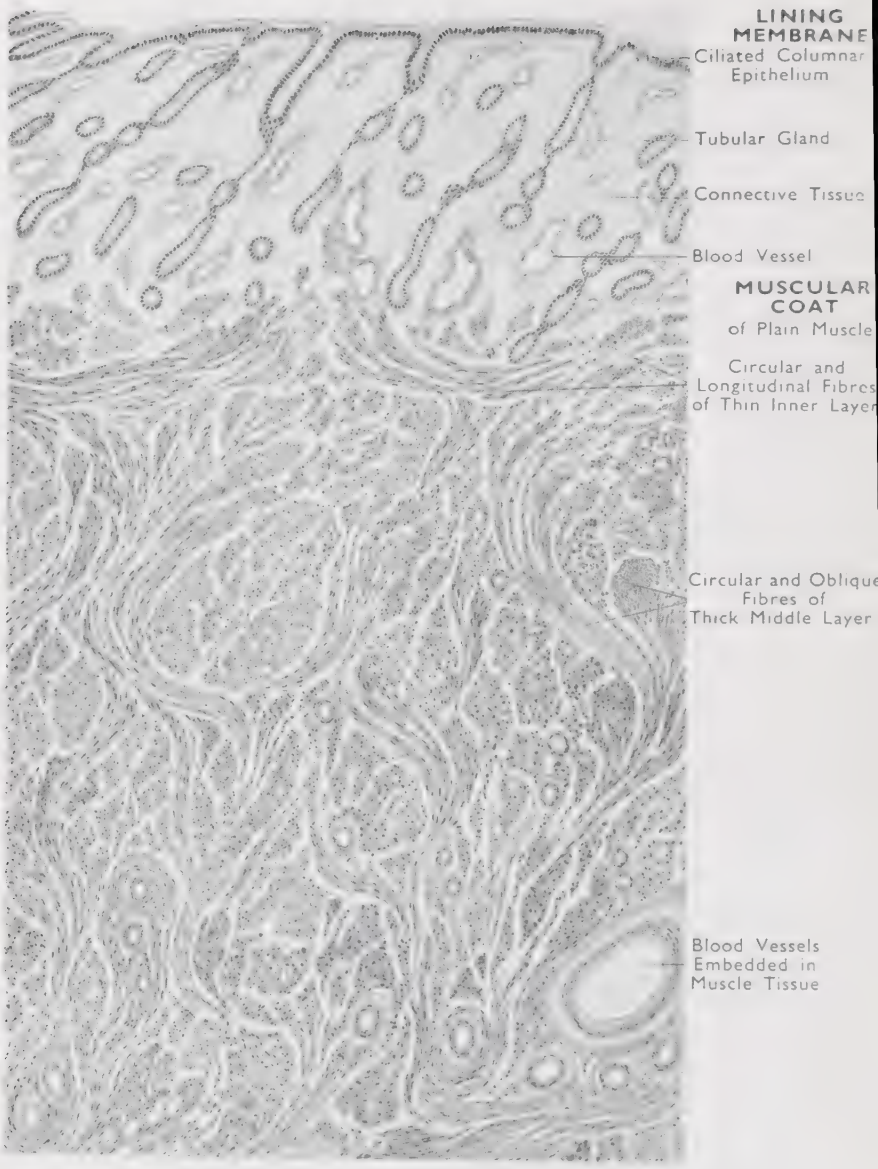


Fig. 93

SECTION OF UTERUS. × 60

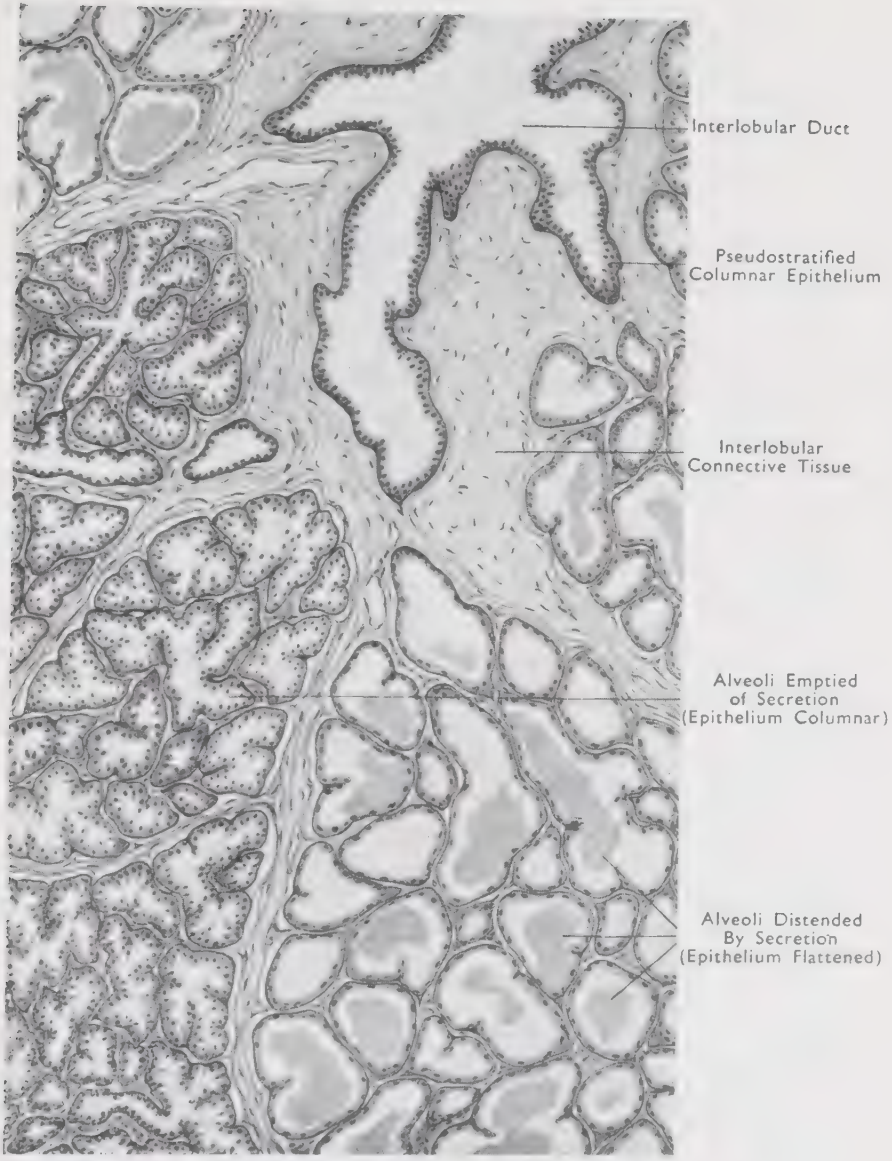


Fig. 94

SECTION OF ACTIVE MAMMARY GLAND. × 80

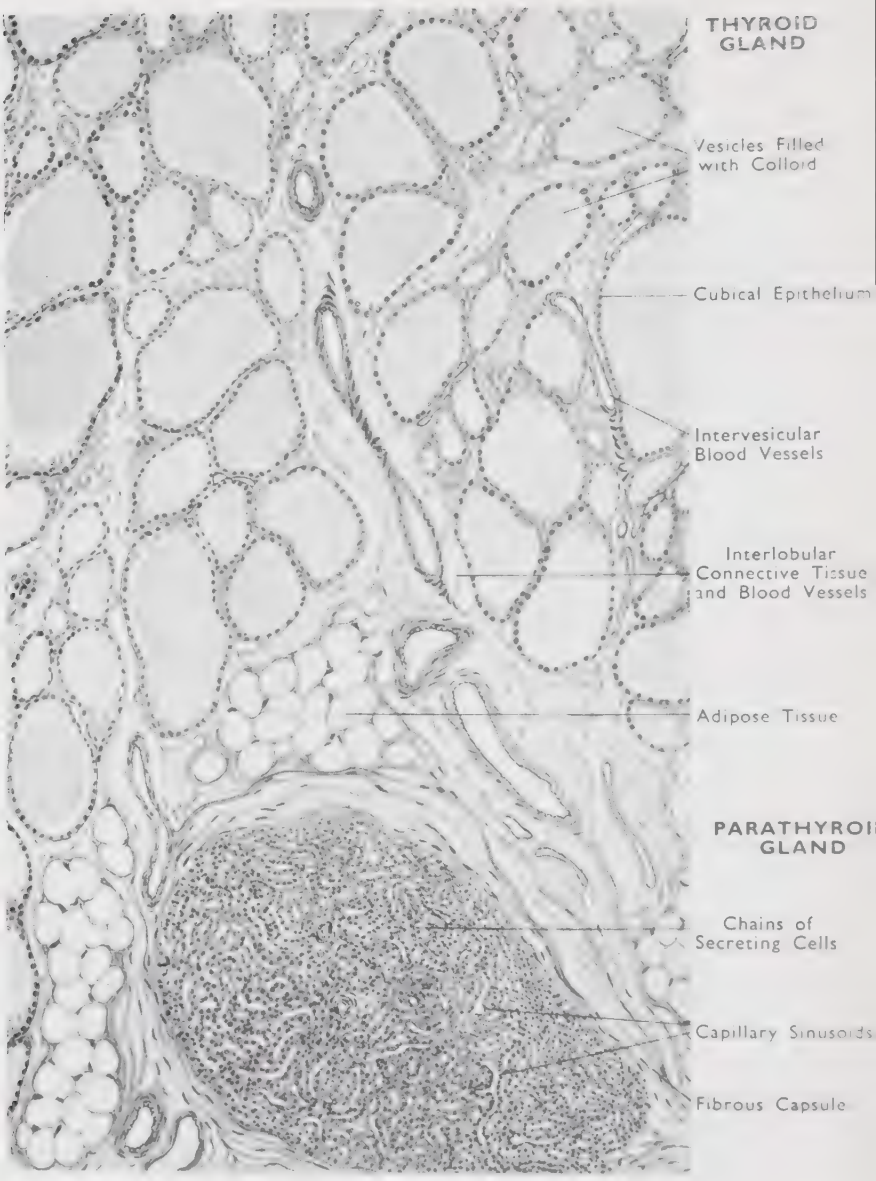


Fig. 95

SECTION OF THYROID AND PARATHYROID GLANDS. × 65

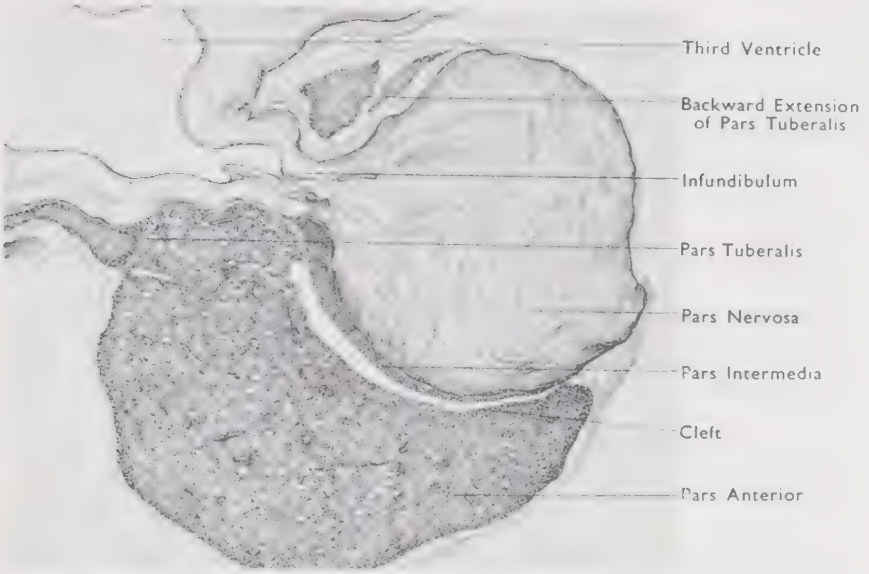


Fig. 96. **SECTION OF PITUITARY GLAND.** SHOWING ITS PRINCIPAL PARTS AND ITS ATTACHMENT TO THE BASE OF THE BRAIN. × 10

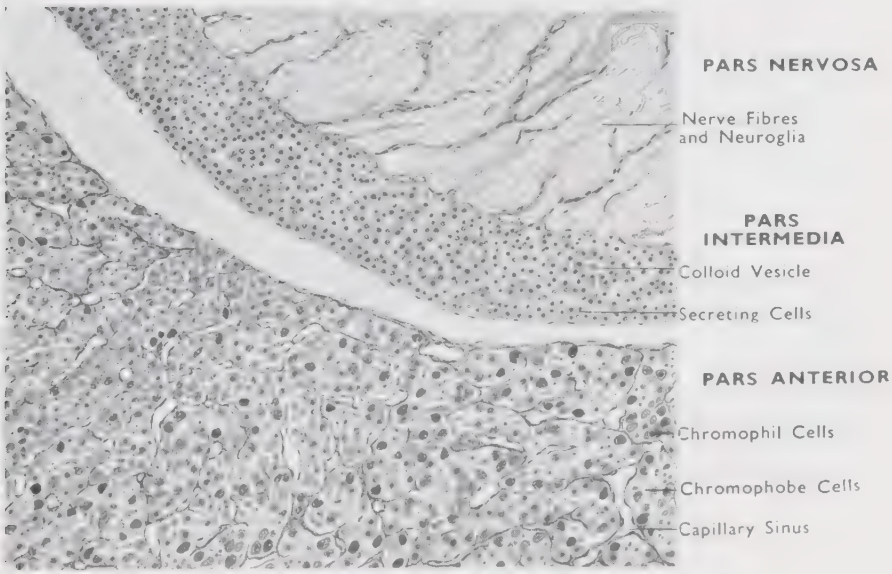


Fig. 97. **SECTION OF PITUITARY GLAND.** × 110

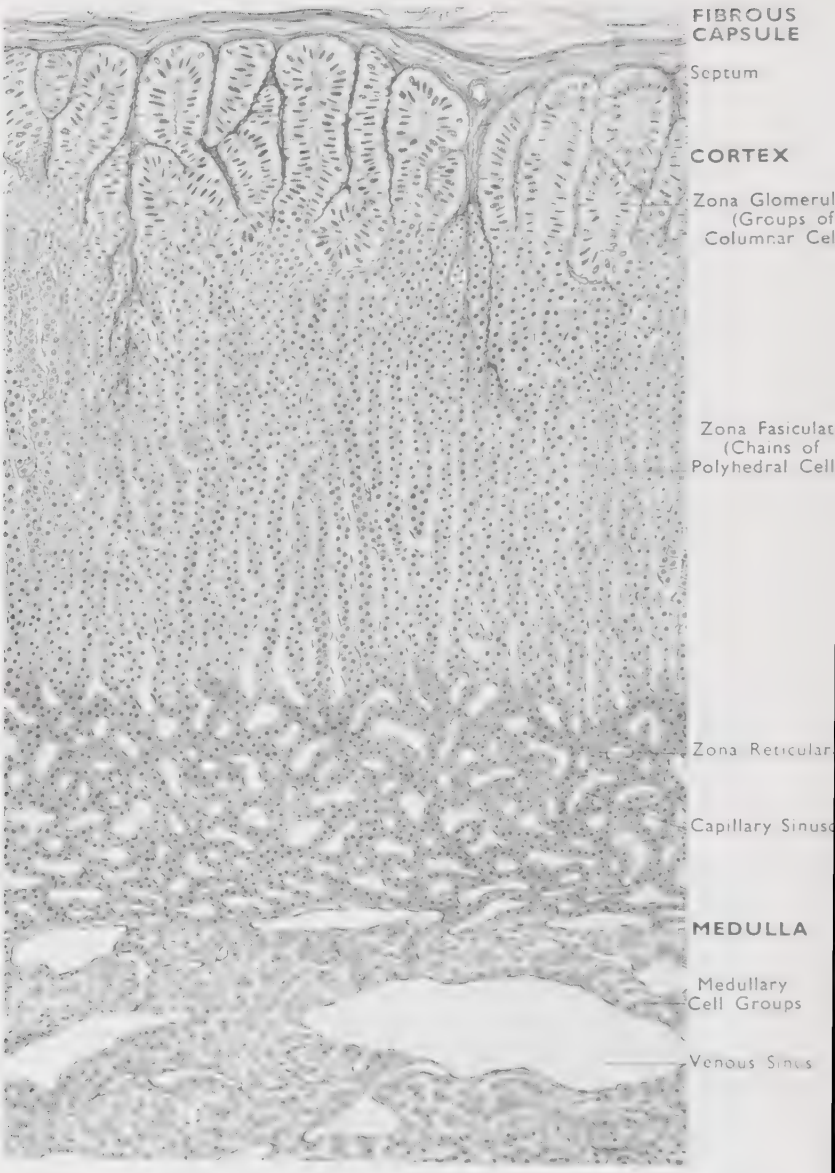


Fig. 98

SECTION OF ADRENAL GLAND. × 120

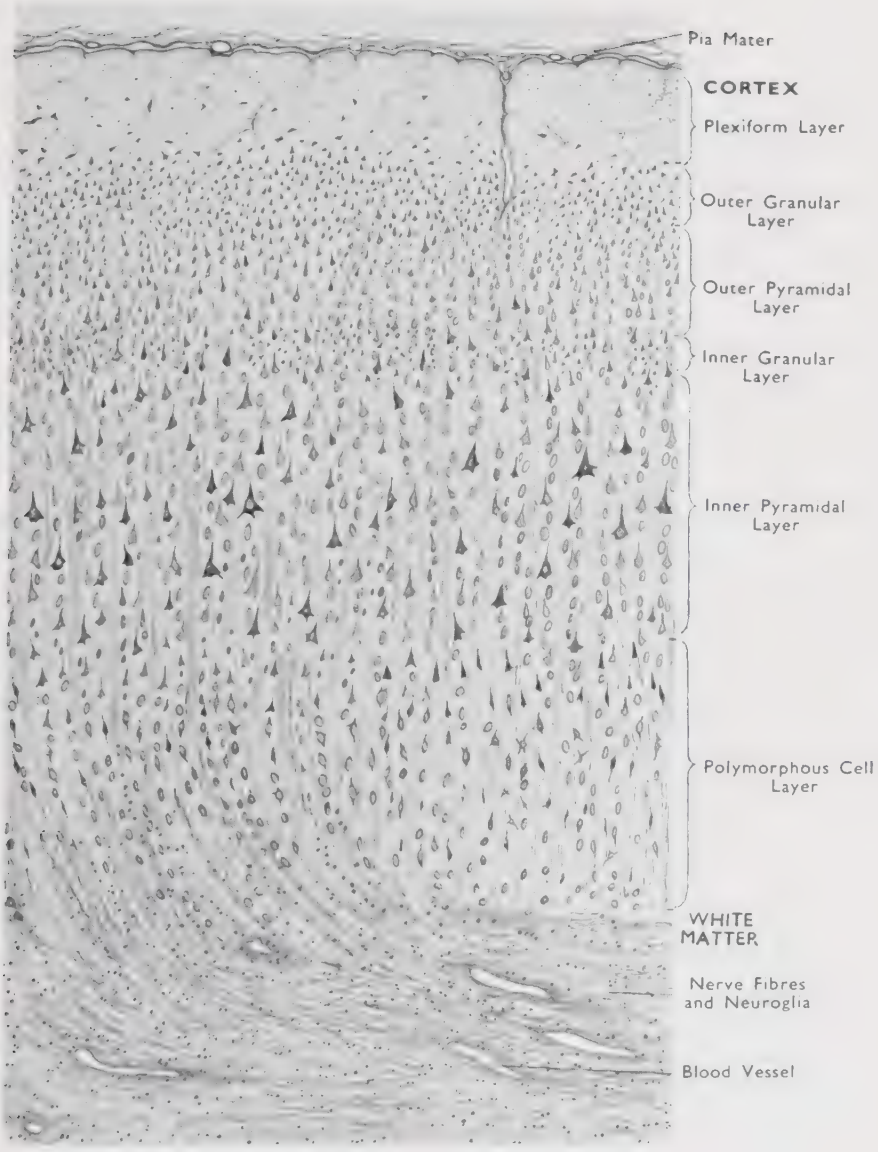


Fig. 99

CEREBRUM

VERTICAL SECTION. × 65

Fig. 100

CEREBELLUM

VERTICAL SECTION. × 40

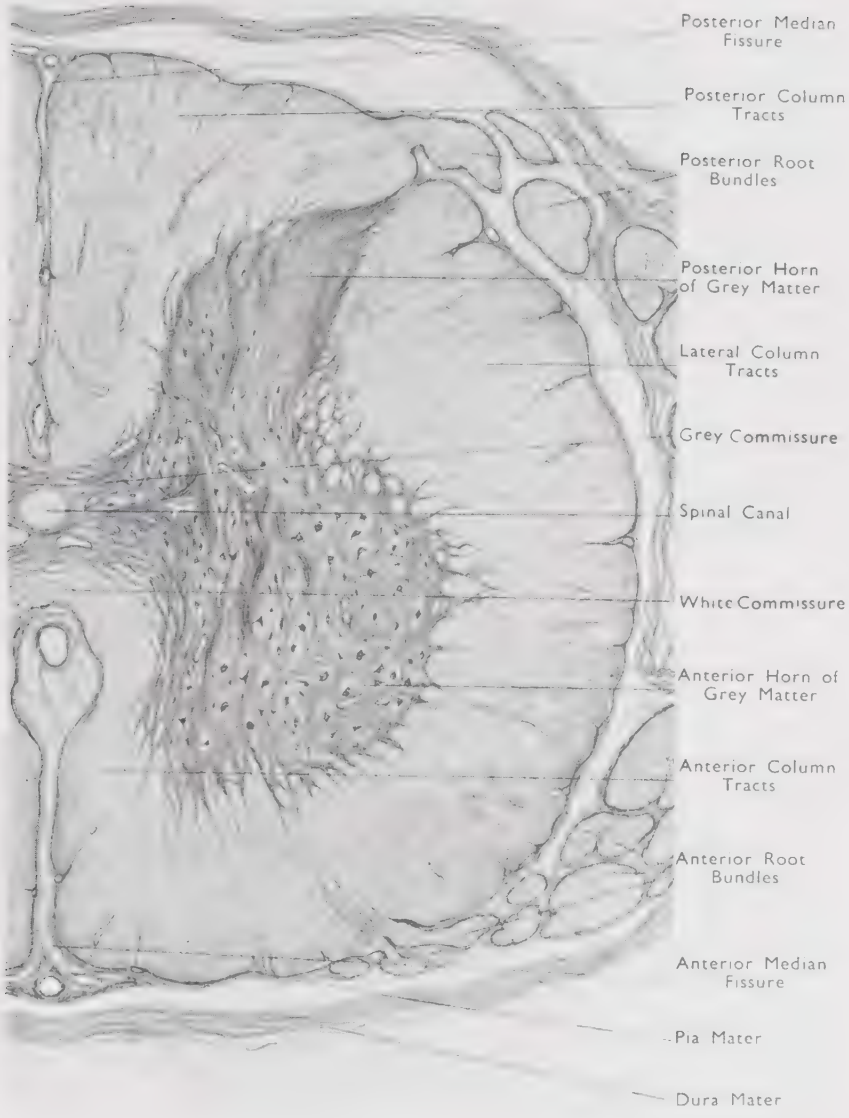


Fig. 101

SPINAL CORD

TRANSVERSE SECTION THROUGH UPPER LUMBAR REGION. × 13

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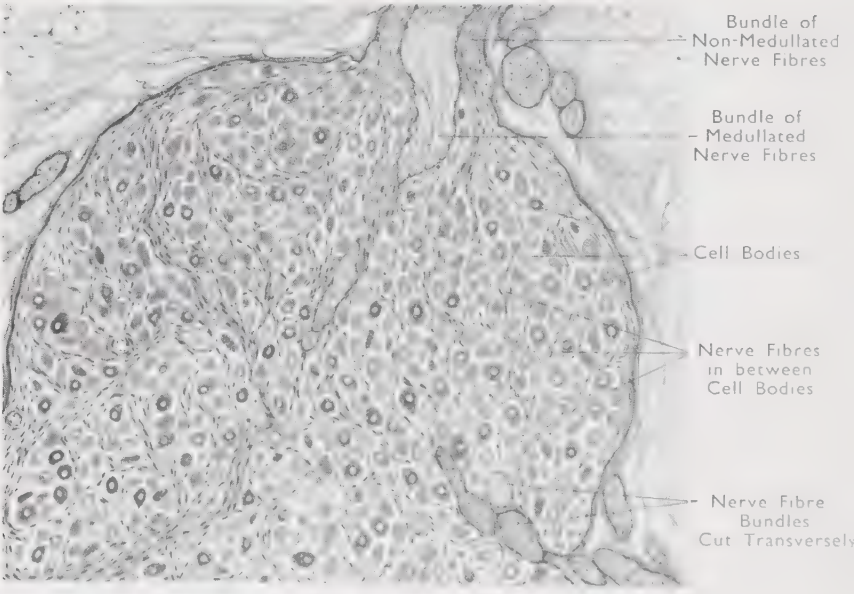

Fig. 103. **SECTION OF SYMPATHETIC GANGLION.** × 50

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